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☐ B. Item temporarily not in stock. Will be supplied upon receipt of material (approximately 30 days). No further follow-up required by requester.

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- ☐ COMMANDER, NAVAL ORDNANCE SYSTEMS COMMAND, WASHINGTON, D.C., 20360
- ☐ COMMANDER, NAVAL SHIP SYSTEMS COMMAND, WASHINGTON, D.C., 20360
- ☐ COMMANDER, NAVAL FACILITIES ENGINEERING COMMAND, WASHINGTON, D.C., 20390
- ☐ COMMANDING GENERAL, AIR FORCE LOGISTICS COMMAND, ATTN: SGEDS, WRIGHT-PATTERSON AFB, DAYTON, OHIO, 45433
- ☐ COMMANDING GENERAL, U.S. ARMY ELECTRONICS COMMAND, 225 S. 18TH ST., PHILADELPHIA, PA., 19103
- ☐ COMMANDING GENERAL, HQ QM R&E CENTER, U.S. ARMY, NATICK, MASS., 01760
- ☐ COMMANDING OFFICER, U.S. NAVAL ORDNANCE PLANT, CENTRAL TECHNICAL DOCUMENT OFFICE, LOUISVILLE, KY., 40214.

☐ L. Items may be purchased from office listed below:

- ☐ SOCIETY OF AUTOMOTIVE ENGR. 485 LEXINGTON AVENUE NEW YORK, NEW YORK, 10017
- ☐ AMERICAN SOCIETY FOR TESTING MATERIALS 1916 RACE STREET PHILADELPHIA, PA., 19103
- ☐ AMERICAN STANDARDS ASSOCIATION, INC. 10 EAST 40TH STREET NEW YORK, NEW YORK, 10016
- ☐ NAT'L STANDARDS ASSOCIATION, INC. 1321 14TH STREET, N.W. WASHINGTON, D.C., 20005
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- ☐ SUPERINTENDENT OF DOCUMENTS GOVERNMENT PRINTING OFFICE WASHINGTON, D.C., 20370
- ☐ AMERICAN WELDING SOCIETY 345 E. 47TH STREET NEW YORK, N.Y., 10017

☐ M. OTHER

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NATIONAL RADIO INSTITUTE

Established 1914

WASHINGTON, D. C.

DISCUSSION SHEET - FOLD AND PLACE WITH LESSON 9FR

There are several places in this lesson where the material is presented in a way that is a decided departure from the conventional manner. For example, we teach you that electromagnetic induction from the primary to the secondary of a transformer is the result of changing flux linkages. While engineers have been talking in terms of flux linkages for years, writers of text books in general have stuck to the old manner of speaking and they talk about conductors cutting lines of force.

Of course we mention this too, but the idea we want you to have after studying this lesson is that changes in flux linkages are responsible for all induced e.m.f.'s. This is all brought out clearly in Figs. 2, 3, 4 and 5. You will notice that we can change the flux linkages in several ways - by moving one of the coils within the other, by moving the larger coil, or by causing the current flowing through one coil to change in magnitude. In any case, there is motion.

Now refer to Fig. 4c. There should of course be a battery in the buzzer circuit. When the switch is closed the buzzer will alternately close and open the circuit and cause the flux about the larger coil to increase and decrease. As the flux moves up and down, its linkages with the smaller coil change and an alternating voltage is induced in the smaller coil.

On page 4 there is a misprint. In the sixth line starting with the last word, change to "The second coil has 100 magnetic lines of force threading through it when maximum current flows in the first coil." On page 6 in the tenth line, we speak of the plate of a tube as a source of e.m.f. You will often see a vacuum tube referred to as a generator of e.m.f. and as the output of the tube is considered as the plate current, the meaning of the sentence will be perfectly clear.

In the seventh line of page 7, change to "lines 1, 2, 3 and 4." Of course, "4" in the next line should be omitted.

Near the bottom of the same page we talk about a complete magnetic circuit. Figure 6b will make clear what is meant. The iron core on which the windings are placed, is closed and the flux can flow right around it, just as current flows in a complete circuit.

In the fourth line of page 9, the statement is made that "The power must be the same." This is true only if there are no losses present in the core. However, there are always some losses so that the output power is always less than the input power. The important thing is that it can't be greater.

On the next page, change 100 in the third and fifth lines to 110 and in the fourth line change 11.5 to 13.6 turns.

The letter L in the fourth line of page 12 refers to the total inductance, including the inductance L1, L2 and the mutual inductance.

On page 15, cross out the whole third sentence under the illustration.

In the eighth line from the bottom of page 19, the printer left out part of the sentence. It should read, "But capacitive reactance shifts phase in a direction opposite to the shift caused by inductive reactance."

On page 24 you will notice the abbreviation μf used twice. This is the same as mfd. In your general reading you will find microfarad abbreviated both ways. On page 28, line fifteen, Fig. C refers to Fig. 21C.

J. A. Dowie, Chief Instructor,
National Radio Institute.

Page 7: Add the following new paragraph:

"4.4 The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the Government. Inspection records of the examination and tests shall be kept complete and available to the Government as specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements."

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Navy - Ships

Preparing activity:
Navy - Ships
(Project 5330-0072)

MILITARY SPECIFICATION

RUBBER SHEETS, STRIPS, AND GASKETS;

SOLID, SYNTHETIC, MEDIUM AND MEDIUM HARD

This amendment, which forms a part of Military Specification MIL-R-1149A, 9 April 1956, has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy and the Air Force.

Page 3, paragraph 3.6.1: Delete and substitute:

"3.6.1 The hardness of the synthetic rubber shall have indentation values within the following ranges. The approximate shore "A" durometer values are included for convenient reference.

Hardness, all classes.

Thickness nominal	Type I		Type II	
	Indentation	Shore "A" durometer	Indentation	Shore "A" durometer
Inch	Millimeters		Millimeters	
1/4	1.12 - 1.42	47 - 56	0.66 - 0.96	62 - 72
5/16	1.14 - 1.44	47 - 55	.68 - .98	61 - 72
3/8	1.16 - 1.46	46 - 55	.68 - .98	61 - 72
7/16	1.18 - 1.48	45 - 54	.70 - 1.00	60 - 71
1/2	1.20 - 1.50	45 - 53	.70 - 1.00	60 - 71

Page 3, paragraph 3.6.2.4: Delete.

Page 3, paragraph 4.1.2, line 2: Delete "inspection" and substitute "examination".

Page 3, paragraph 4.1.2.1, first sentence: Delete and substitute: "For the examination specified in 4.2.1, respresentative samples shall be selected from different portions of each lot in accordance with table III."

FSC 5330

Page 4, paragraph 4.1.2.2, first sentence: Delete and substitute: "For examination specified in 4.2.1, representative samples shall be selected from different portions of each lot in accordance with table IV."

Page 4, paragraph 4.1.3.1, first sentence: Delete and substitute: "For the tests specified in 4.2.2, four samples shall be selected from each lot."

Page 4, paragraphs 4.1.3.1 and 4.1.3.2.2, second sentence: Delete "which, in the opinion of the Government inspector, are" and substitute "are considered".

Page 4, paragraph 4.1.3.2.2, lines 5 and 6: Delete "the Government inspector shall select 4 samples" and substitute "four samples shall be selected".

Page 4, paragraph 4.1.3.2.3: Delete and substitute:

"4.1.3.2.3 Sampling for compression tests. - When the size and shape of the material in the lot are such as to make proper compression set determination possible on samples selected in accordance with 4.1.2.2, four samples shall be selected from the lot for the test specified in 4.2.2.4. The samples shall be chosen from those of the rolls of gaskets selected in accordance with 4.1.2.2 which are considered the poorest of the lot. When proper compression set determinations on the material comprising the lot are impossible, the contractor shall furnish 3 special sample pieces approximately 4 inches long by 1-1/2 inch in thickness. These sample pieces shall be identical in composition and equivalent in cure; and prepared at the same time from material used in the lot of finished strips and gaskets offered for delivery. At the discretion of the Government, the same sample or samples may be used for the compression tests as were used for the hardness tests (see 4.1.3.2.2 and 4.2.2.3)".

Page 5, paragraph 4.1.4, first sentence: Delete and substitute "From the first lot of material of each class and type offered for delivery under a contract or order, 4 samples 10-inches long, 1-inch wide, or wider, and not less than 1/4-inch thick shall be selected for the tests of 4.2.3."

Page 5, paragraph 4.1.4, third sentence: Delete "inspection and test at the place of manufacture" and substitute "examination and test".

Page 5, paragraphs 4.2 and 4.2.1: Delete and substitute:

"4.2 Examination and tests. -

"4.2.1 Examination. - Each of the samples selected in accordance with 4.1.2 shall be subjected to surface examination for workmanship, dimensions, and tolerances. Minor surface defects not affecting the serviceability of the material shall not be cause for rejection. If any one of the samples is found to be not in conformance with the requirements of 3.3, 3.4, and 3.5, the entire lot which it represents shall be rejected."

Page 5, paragraph 4.2.2.1: Delete.

Page 5, paragraph 4.2.2.5: Delete and substitute:

"4.2.2.5 Rejection. - If any one of the samples representing a lot is found to be not in conformance with this specification, the entire lot shall be rejected."

Page 6, paragraphs 4.2.3 through 4.2.3.3: Delete and substitute:

"4.2.3 Production check test. - Each of the samples selected in accordance with 4.1.4 shall be subjected individually to the flexibility, extraction, and specific gravity tests specified in 4.3.5, 4.3.6 and 4.3.7.

"4.2.3.1 Action in case of failure. - Acceptance of the first lot offered for delivery shall be withheld pending receipt of a satisfactory test report on the samples representing the lot. Thenceforth, except as hereinafter specified, acceptance and rejection of lots shall normally be on the basis of the sampling, examination and tests of 4.1.2, 4.1.3, 4.2.1 and 4.2.2, and acceptance shall not be withheld pending receipt of test reports on production check test samples. However, upon receipt of an unsatisfactory report on any sample chosen for production check test, additional samples shall be selected from every subsequent lot of the same type, class and thickness offered for delivery. These samples shall be subjected to the tests wherein failure was observed. Lots shall then be accepted only upon receipt of a satisfactory test report on the samples so selected. This additional testing shall be discontinued and lot acceptance returned to the normal basis when four successive lots have been accepted."

Page 6, paragraph 4.3.2: Delete and substitute:

"4.3.2 Hardness test. - The hardness shall be determined by method 3031 of Test Method Std. No. 601."

FOLD

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MIL-R-1149A
9 APRIL 1956
SUPERSEDING
JAN-R-1149
27 JUNE 1949

MILITARY SPECIFICATION

RUBBER SHEETS, STRIPS, AND GASKETS; SOLID, SYNTHETIC, MEDIUM AND MEDIUM HARD

This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.

1. SCOPE

1.1 Scope.—This specification covers synthetic rubber compounds for medium and medium hard synthetic rubber gaskets except for hatches, airports, and watertight and airtight doors for shipboard use.

1.2 Classification.—Synthetic rubber shall be of the following types and classes as specified (see 6.1):

Type I—Medium.

Class 1—Compound utilizing polymerized chloroprene as the basic material.

Class 2—Compound utilizing a copolymer product of butadiene and styrene as the basic material.

Class 3—Compound utilizing a copolymer product of isobutylene and isoprene.

Class 5—Compound utilizing a copolymer product of butadiene and acrylonitrile nitrile of the basic material.

Type II—Medium Hard.

Class 1—Compound utilizing polymerized chloroprene as the basic material.

Class 2—Compound utilizing a copolymer product of butadiene and styrene as the basic material.

Class 3—Compound utilizing a copolymer product of isobutylene and isoprene.

Class 5—Compound utilizing a copolymer product of butadiene and acrylonitrile nitrile of the basic material.

2. APPLICABLE DOCUMENTS

2.1 The following specifications and standards, of the issue in effect on date of invitation for bids, form a part of this specification:

SPECIFICATIONS

FEDERAL

NN-B-591 —Boxes, Fiberboard, Wood-Cleated (for Domestic Shipment).
NN-B-621 —Boxes, Wood, Nailed and Lock Corner.
LLL-B-631 —Boxes; Fiber, Corrugated (for Domestic Shipment).
LLL-B-636 —Boxes, Fiber, Solid (for Domestic Shipment).
PPP-B-601 —Boxes, Wood-Cleated-Plywood.
PPP-B-585 —Boxes; Wood, Wirebound.

FED. SUP. CLASS.
5330, 9320

MILITARY

JAN–P–103 —Packaging and Packing for Overseas Shipment—Boxes; Wood Cleated; Solid Fiberboard.

MIL–B–107 —Boxes, Wood, Wirebound (Overseas Type).

JAN–P–108 —Packaging and Packing for Overseas Shipment—Boxes, Fiberboard (V-Board and W-Board), Exterior and Interior.

MIL–P–116 —Preservation, Methods of.

MIL–L–10547 —Liners, Case, Waterproof.

STANDARDS

FEDERAL

FED. STD. No. 601—Rubber, Sampling and Testing.

MILITARY

MIL–STD–129—Marking for Shipment and Storage.

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

2.2 Other publications.—The following document forms a part of this specification. Unless otherwise indicated the issue in effect on date of invitation for bids shall apply.

CONSOLIDATED CLASSIFICATION COMMITTEE

Consolidated Freight Classification Rules.

(Application for copies should be addressed to the Consolidated Classification Committee, 202 Chicago Union Station, Chicago 6, Ill.)

3. REQUIREMENTS

3.1 Material.—The synthetic rubber material shall be as specified hereinafter. The material shall be free from all defects and imperfections that might affect the serviceability of the finished product.

3.2 Synthetic rubber shall be furnished in the form of sheets, strips, or cut or molded gaskets as specified (see 6.1).

3.3 Sheet rubber.—Sheet rubber shall be of uniform thickness; shall have a smooth or fine fabric impression surface as specified (see 6.1); and shall be furnished in rolls 36 inches ± 1 inch wide and within the thickness tolerances specified in 3.5.

3.4 Gaskets.—When gaskets are required, they shall be molded, stamped, or cut from sheets or tubing, as specified (see 6.1); and shall be of the shape and dimensions specified in the contract or order and within the tolerances specified in 3.5.

3.5 Tolerances.—

3.5.1 *Tolerances in width.*—For strip synthetic rubber, unless otherwise specified in the contract or order, tolerances in width will be permitted as shown in table I.

TABLE I.—*Tolerance in width.*

Width	Tolerance (plus or minus)
Inches	Inch
Less than 1/16 inch	0.010
Over 1/16 to 1/8, inclusive	1/64
Over 1/8 to 1/2, inclusive	1/32
Over 1/2 to 1, inclusive	3/64
Over 1 to 2	1/16
Over 2	3 percent

3.5.2 *Tolerance in thickness.*—For sheet, and strip synthetic rubber, tolerances in thickness will be permitted as shown in table II.

TABLE II.—*Tolerance in thickness.*

Thickness	Tolerance (plus or minus)
Inch	Inch
1/32 up to 1/16	1/128
Over 1/16 to 1/8, inclusive	1/64
Over 1/8 to 1/2, inclusive	1/32
Over 1/2 to 1, inclusive	3/64
Over 1	1/16

3.5.3 *Tolerances for cut, molded and extruded parts.*—Tolerances for cut, molded and extruded parts shall be as specified (see 6.1).

3.6 Physical requirements.—The synthetic rubber shall conform to the following physical requirements:

3.6.1 *Before aging.*—

	Type I	*Type II*
Tensile strength minimum, pounds per square inch	1000	1000
Ultimate elongation, minimum, percent	300	250

Hardness, all classes

Thickness, nominal	*Type I*		*Type II*	
	Indentation, minimum Millimeters	Approx. shore A durometer	Indentation, minimum Millimeters	Approx. shore A durometer
Inch				
1/4	1.12	56	0.66	70
5/16	1.14	55	.68	69
3/8	1.16	54	.68	69
7/16	1.18	54	.70	68
1/2	1.20	53	.70	68

3.6.2 *After oven aging.*—The synthetic rubber, after being subjected to the oven aging test specified in 4.3.4, shall meet the following requirements:

3.6.2.1 *Tensile strength.*—The tensile strength shall be not less than 80 percent of the tensile strength of unaged specimens.

3.6.2.2 *Elongation.*—The ultimate elongation shall be not less than 65 percent of the elongation of the unaged specimens.

3.6.2.3 *Compression set.*—The compression set, determined by the method described in 4.3.3, shall be not more than 75 percent.

3.6.2.4 *Hardness.*—The hardness determined by the method specified in 4.3.2 shall be not less than 1.00 millimeter indentation (60 max. Shore A durometer) for type I and 0.60 millimeter indentation (75 max. Shore A durometer) for type II.

3.7 Flexibility (at minus 20° ± 2°F.).—A strip of synthetic rubber, 1/4 inch thick by 1 inch wide, shall require not more than the following loads to deflect the distances indicated from the horizontal, when subjected to the test specified in 4.3.5.

Deflection (in inches)	Load required (in grams) at minus 20° ± 2°F.
1	50 max.
2	70 max.

3.8 Extraction in distilled water.—When tested as specified in 4.3.6, synthetic rubber shall show not more than 0.5 percent extraction by weight.

3.9 Specific gravity.—The specific gravity of the rubber compound shall be not greater than the following:

	Type I	*Type II*
Class 1	1.65	1.75
Class 2	1.55	1.65
Class 3	1.55	1.65
Class 5	1.55	1.65

3.10 Workmanship.—The workmanship shall be first class in every respect.

4. QUALITY ASSURANCE PROVISIONS

4.1 Sampling.—

4.1.1 *Lot.*—For purposes of sampling, a lot shall be defined by the following conditions:

(a) It shall consist of not more than 2500 pounds of material of one type and class, produced in one plant under essentially the same conditions.

(b) It shall consist entirely of sheets or of strips 1-1/2 inches wide or wider, or of strips less than 1-1/2 inches wide, or of gaskets 1-1/2 inches wide or wider, or of gaskets less than 1-1/2 inches wide.

(c) All material in the lot shall be of the same thickness.

4.1.2 *Sampling procedure for lot acceptance inspection.*—

4.1.2.1 *Sheets and strips 1-1/2 inches wide or wider, and gaskets 1-1/2 inches wide or wider.*—For the inspection specified in 4.2.1, the Government inspector shall select representative samples from different portions of each lot in accordance with table III. The samples from each lot shall be chosen so that a representative selection of sizes and shapes will be obtained.

TABLE III—*Sheets and strips 1-1/2 inches wide or wider, and gaskets 1-1/2 inches wide or wider.*

Number of rolls of sheets or strips or number of gaskets in the lot	Number of sample rolls or gaskets to be selected
1-11	All
12-50	11
Over 50	14

4.1.2.2 *Strips less than 1-1/2 inches wide, and gaskets less than 1-1/2 inches wide.*—For inspection specified in 4.2.1, the Government inspector shall select representative samples from different portions of each lot in accordance with table IV. The samples from each lot shall be chosen so that a representative selection of sizes and shapes will be obtained.

TABLE IV—*Strips less than 1-1/2 inches wide, and gaskets less than 1-1/2 inches wide.*

Number of rolls of strip or number of gaskets in lot	Number of rolls or gaskets to be selected
1-25	All
26-50	22
51-100	27
101-400	33
Over 400	36

4.1.3 *Sampling procedure for lot acceptance tests.*—

4.1.3.1 *Sheets and strips 1-1/2 inches wide or wider, and gaskets 1-1/2 inches wide or wider.*—For the tests specified in 4.2.2, the Government inspector shall select 4 samples from each lot. Each sample shall consist of a quantity of material sufficient to perform all tests specified in 4.2.2. The samples shall be chosen from those of the rolls or gaskets selected in accordance with 4.1.2.1 which, in the opinion of the Government inspector, are the poorest of the lot. Samples of sheets or strips shall each be of the size indicated in table V, and, if possible, no two samples shall be selected from the same roll.

TABLE V—*Sheets and strips 1-1/2 inches wide or wider, and gaskets 1-1/2 inches wide or wider.*

		Square feet
Sheet	Thicknesses less than 1/2 inch	1
	Thicknesses 1/4 up to 3/4 inch	1/2
	Thicknesses 3/4 to 1-1/4 inches, inclusive	1/4
		Linear feet
Strip		5

4.1.3.2 *Strips less than 1-1/2 inches wide and gaskets less than 1-1/2 inches wide.*—

4.1.3.2.1 *Sampling for tension and elongation tests.*—For the tests specified in 4.2.2.2, the contractor shall furnish 2 sample pieces 6 inches long by 6 inches wide by 0.080 ± 0.010 inch thick. These pieces shall be identical in composition and equivalent in cure; and prepared at the same time from material used in the lot of finished strips offered for delivery.

4.1.3.2.2 *Sampling for hardness tests.*—When the size and shape of the material in the lot are such as to make proper hardness determinations possible on samples selected in accordance with 4.1.2.2, the Government inspector shall select 4 samples from the lot for the test specified in 4.2.2.3. The samples shall be chosen from those of the rolls or gaskets selected in accordance with 4.1.2.2 which, in the opinion of the Government inspector, are the poorest of the lot. When proper hardness determinations of the material comprising the lot are impossible, the contractor shall furnish 1 sample piece approximately 4 inches long by 1-1/2 inches wide and 1/2 inch in thickness. This sample piece shall be identical in composition and equivalent in cure; and prepared at the same time from material used in the lot of finished strips offered for delivery.

4.1.3.2.3 *Sampling for compression tests.*—When the size and shape of the material in the lot are such as to make proper compression set determination possible on samples selected in accordance with 4.1.2.2 the Government inspector shall select 4 samples from the lot for the test specified in 4.2.2.4. The samples shall be chosen from those of the rolls or gaskets selected in accordance with 4.1.2.2 which, in the opinion of the Government inspector, are the poorest of the lot. When proper compression set determinations on the material comprising the lot are impossible, the contractor shall furnish 3 special sample pieces approximately 4 inches long by 1-1/2 inches wide and 1/2 inch in thickness. These sample pieces shall be identical in composition and equivalent in cure; and prepared at the same time from material used in the lot of finished strips and gaskets offered for delivery. At the discretion of the Government inspector, the same sample or samples may be used for the compressure tests as were used for the hardness tests (see 4.1.3.2.2 and 4.2.2.3).

4.1.4 *Sampling for production check tests.*—From the first lot of material of each class and type offered for delivery under a contract or order, the Government inspector shall select 4 samples 10 inches long, 1 inch wide, or wider, and not less than 1/4 inch thick for the tests of 4.2.3. If the sizes of material in the lot are too small to permit selection of samples from the lot, the contractor shall furnish 4 samples of the required size which shall be identical in composition and equivalent in cure with the packing or gaskets of the lot and to have been prepared at the same time as the lot from materials used in preparation of the lot. Thenceforth 4 such samples shall be furnished for every 10 lots which have passed inspection and test at the place of manufacture. These samples shall be chosen so that a representative selection of sizes, shapes, and thicknesses will be obtained during the course of the contract or order.

4.2 Inspection and tests.—

4.2.1 *Lot acceptance inspection at place of manufacture.*—Each of the samples selected in accordance with 4.1.2 shall be subjected by the Government inspector to surface inspection for workmanship, dimensions, and tolerances. Minor surface defects not affecting the serviceability of the material shall not be cause for rejection. If any one of the samples is found to be not in conformance with the requirements of 3.3, 3.4, and 3.5, the entire lot which it represents shall be rejected. A rejected lot may be resubmitted for Government inspection, but only after the manufacturer, subsequent to the first Government inspection, has inspected the lot 100 percent for the deficiency noted and has removed all nonconforming packing or gaskets.

4.2.2 *Lot acceptance tests.*—

4.2.2.1 *Place of test.*—Lot acceptance tests shall be made at the place of manufacture if facilities are available. Otherwise, lot acceptance tests shall be made at the Material Laboratory, New York Naval Shipyard, Naval Base Station, Brooklyn 1, N. Y.

4.2.2.2 *Tensile strength and elongation.*—The samples selected in accordance with 4.1.3.1 or 4.1.3.2.1 (as applicable) shall be subjected to the following tests:

(a) Initial tensile strength (see 4.3.1).

(b) Initial ultimate elongation (see 4.3.1).

(c) Tensile strength after oven aging (see 4.3.1 and 4.3.4).

(d) Ultimate elongation after oven aging (see 4.3.1 and 4.3.4).

Where 4 samples are chosen to represent a lot in accordance with 4.1.3.1 each of the 4 samples shall be evaluated separately.

4.2.2.3 *Hardness test.*—The hardness of the samples (or sample) selected in accordance with 4.1.3.1 or 4.1.3.2.2, as applicable, shall be determined by the method described in 4.3.2. Where 4 samples are selected to represent a lot, the hardness of each of the 4 samples shall be evaluated separately.

4.2.2.4 *Compression set.*—The samples (or sample) selected in accordance with 4.1.3.1 or 4.1.3.2.3, as applicable, shall be subjected to the test described in 4.3.3. Where 4 samples are chosen to represent a lot, each of the 4 samples shall be evaluated separately. The compression set value for each sample shall be the average of 2 determinations.

4.2.2.5 *Rejection.*—If any one of the samples representing a lot is found to be not in conformance with this specification, the entire lot shall be rejected. At the option of the manufacturer, a rejected lot may be recured or otherwise reworked to remove the deficiencies which caused rejection, and may then be resubmitted for Government inspection. In this case, the lot shall be resampled by the Government inspector in accordance with 4.1.2 and 4.1.3 and shall be subjected to all inspection and tests specified in 4.2.1 and 4.2.2.2 to 4.2.2.4, inclusive.

4.2.3 *Production check tests.*—

4.2.3.1 *Place of test.*—Production check tests shall be made at the Material Laboratory, New York Naval Shipyard, Naval Base Station, Brooklyn 1, N. Y., and samples therefor shall be forwarded by the Government Inspector.

4.2.3.2 *Test procedure.*—Each of the samples selected in accordance with 4.1.4 shall be subjected individually to the flexibility, extraction, and specific gravity tests specified in 4.3.5, 4.3.6 and 4.3.7.

4.2.3.3 *Action in case of failure.*—Acceptance of the first lot offered for delivery shall be withheld pending receipt of a satisfactory test report on the samples representing the lot. Thenceforth, except as hereinafter specified, acceptance and rejection of lots shall normally be on the basis of the sampling, inspection and tests of 4.1.2, 4.1.3, 4.2.1 and 4.2.2, and acceptance shall not be withheld pending receipt of test reports on production check test samples. However, upon receipt of an unsatisfactory test report on a production check test sample, the Government inspector shall select additional samples from every subsequent lot of the same type, class and thickness offered for delivery. The samples so selected shall be submitted to the Government laboratory, and shall there be subjected to the tests wherein failure occurred. Lots shall then be accepted only upon receipt of a satisfactory test report on the samples so selected. This additional testing shall be discontinued and lot acceptance returned to the normal basis of 4.1.2, 4.1.3, 4.2.1 and 4.2.2 when 4 successive lots have been accepted.

4.3 Method of tests.—

4.3.1 *Tension tests.*—Methods of test and type III test specimens for tensile strength and elongation of methods 4111 and 4121 of Test Method Standard No. 601 shall be used.

4.3.2 *Hardness test.*—The hardness shall be determined by methods 3021 and 3031 of Test Method Standard No. 601.

4.3.3 *Compression set.*—

4.3.3.1 *Apparatus.*—The compression device shall consist of 2 or more flat steel plates between the parallel faces of which the specimens may be compressed. Steel spacers 0.150 inch thick shall be placed on each side of the rubber specimens to control their thickness to a compression of 40 percent. Four bolts shall pass through holes at the corners of the plates for compressing and holding the specimens.

4.3.3.2 *Test specimens.*—The test specimens shall be 1.129 inches in diameter by 1/2 inch thick, cut and buffed to within a permissible variation of plus or minus 0.005 inch in any dimension.

4.3.3.3 *Measurements.*—The thickness, before and after the compression-set test, shall be measured to the nearest 0.001 inch at the center of each specimen on a dial gage graduated in thousandths of an inch, having a spherical foot 1/4 inch in diameter, exerting a total pressure of 3 ounces ± 0.1 ounce.

4.3.3.4 *Procedure.*—The test specimen, clamped to the specified 40 percent compression, shall be subjected to the oven aging test at 158° ± 2°F. specified in 4.3.4.

4.3.3.5 *Computation.* — The compression set shall be computed in accordance with the following formula:

$$\text{Compression set (percent)} = \frac{t_o - t_1}{t_o - t_s} \times 100$$

Where:

t_o = the original thickness of the test specimen.

t_1 = the thickness of the test specimen 30 minutes after removal from the clamp.

t_s = the thickness of the steel spacers.

4.3.4 *Aging test.*—Specimens for tension, ultimate elongation, and compression set tests shall be given an accelerated aging test by subjecting them to dry circulating air at a temperature of 158° ± 2°F. for 94 hours. Final determination of aged tension-test and ultimate elongation specimens shall be made not less than 20 hours after removal from the oven. Tension and ultimate elongation tests on unaged specimens shall be made immediately prior to, and on the same machine as the tests on the aged specimens.

4.3.5 *Flexibility test.*—The flexibility test shall be in accordance with method 5211 of Test Method Standard No. 601 except that each sample shall be tested at minus 20° ± 2°F. and no correction shall be made for specific gravity.

4.3.6 *Extraction in distilled water.*—The percent extraction shall be determined by the method described in method 6621 of Test Method Standard No. 601 except that an electric hot plate shall not be used in the evaporation to dryness.

4.3.7 *Specific gravity.*—The specific gravity shall be determined by method 14011 of Test Method Standard No. 601.

5. PREPARATION FOR DELIVERY

5.1 Packaging.—

5.1.1 *Level A.*—

5.1.1.1 *Sheets and strips.*—Rubber sheets and strips, in rolls, shall be wrapped in 30-pound minimum basis weight kraft.

5.1.1.2 *Sections.* — Rubber sections and gaskets shall be individually wrapped or packaged in accordance with method III of Specification MIL–P–116.

5.1.2 *Level C.*—The subject material shall be packaged in accordance with commercial practice.

5.2 Packing.—

5.2.1 *Level A.* — The packaged sheets, strips, sections, and gaskets shall be packed in wood cleated fiberboard, cleated plywood, nailed wood, wirebound or fiberboard boxes conforming to Specifications JAN–P–103, PPP–B–601 (overseas type), MIL–B–107 and JAN–P–108, respectively. The gross weight of wood or wood cleated boxes shall not exceed approximately 200 pounds; fiberboard boxes, 70 pounds. The boxes, except those conforming to Specification JAN–P–108 and sealed as specified therein, shall be lined with sealed case liners conforming to Specification MIL–L–10547.

5.2.2 *Level B.* — The packaged sheets, strips, sections and gaskets shall be packed in cleated fiberboard, cleated plywood, nailed wood, wirebound, corrugated or solid fiberboard boxes conforming to Specification NN–B–591, PPP–B–601 (domestic type), NN–B–621, PPP–B–585 or the special requirements of Specifications LLL–B–631 and LLL–B–636, respectively. The gross weight of wood or wood cleated boxes shall not exceed approximately 200 pounds.

5.2.3 *Level C.* — The material shall be packed to insure carrier acceptance and safe delivery to destination at the lowest applicable rate. Containers shall comply with the Consolidated Freight Classification Rules or other carrier regulations applicable to the mode of transportation.

5.3 Marking.—In addition to any special marking required in the contract or order, marking of the packages and shipping containers shall be in accordance with Standard MIL–STD–129.

6. NOTES

6.1 Ordering data. — Procurement documents should specify the following:

(a) Title, number, and date of this specification.

(b) Type and class required (see 1.2).

(c) Form of material required (see 3.2).

(d) Finish required (see 3.3).

(e) Dimensions required (see 3.3 and 3.4).

(f) Shape of gaskets required (see 3.4).

(g) Tolerances required for cut, molded and extruded parts (see 3.5.3).

(h) Whether the material shall be packaged in accordance with level A or C and packed in accordance with level A, B, or C (see 5.1 and 5.2).

6.2 Type I was formerly covered by Navy Specification 33R1h and Military Specification JAN–R–1149.

Patent notice. When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Custodians:
Army—Corps of Engineers
Navy—Bureau of Ships

Other Interest:
Army—CQT
Navy—AOrY.

G48893

SPECIFICATION ANALYSIS SHEET

Form Approved
Budget Bureau No. 119-R004

INSTRUCTIONS

This sheet is to be filled out by personnel either Government or contractor, involved in the use of the specification in procurement of products for ultimate use by the Department of Defense. This sheet is provided for obtaining information on the use of this specification which will insure that suitable products can be procured with a minimum amount of delay and at the least cost. Comments and the return of this form will be appreciated. Fold on lines on reverse side, staple in corner, and send to preparing activity *(as indicated on reverse hereof)*.

SPECIFICATION

ORGANIZATION *(Of submitter)* | CITY AND STATE

CONTRACT NO. | QUANTITY OF ITEMS PROCURED | DOLLAR AMOUNT $

MATERIAL PROCURED UNDER A

☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE SPECIFICATION CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?

A. GIVE PARAGRAPH NUMBER AND WORDING.

B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES.

2. COMMENTS ON ANY SPECIFICATION REQUIREMENT CONSIDERED TOO RIGID

3. IS THE SPECIFICATION RESTRICTIVE?

☐ YES ☐ NO IF "YES", IN WHAT WAY?

4. REMARKS *(Attach any pertinent data which may be of use in improving this specification. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity)*

SUBMITTED BY *(Printed or typed name and activity)* | DATE

DD FORM 1 APR 63 1426 REPLACES NAVSHIPS FORM 4863, WHICH IS OBSOLETE PLATE NO. 15419

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MIL-R-1149A
9 APRIL 1956
SUPERSEDING
JAN-R-1149
27 JUNE 1949

MILITARY SPECIFICATION

RUBBER SHEETS, STRIPS, AND GASKETS; SOLID, SYNTHETIC, MEDIUM AND MEDIUM HARD

This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.

1. SCOPE

1.1 Scope.—This specification covers synthetic rubber compounds for medium and medium hard synthetic rubber gaskets except for hatches, airports, and watertight and airtight doors for shipboard use.

1.2 Classification.—Synthetic rubber shall be of the following types and classes as specified (see 6.1):

Type I—Medium.

Class 1—Compound utilizing polymerized chloroprene as the basic material.

Class 2—Compound utilizing a copolymer product of butadiene and styrene as the basic material.

Class 3—Compound utilizing a copolymer product of isobutylene and isoprene.

Class 5—Compound utilizing a copolymer product of butadiene and acrylonitrile nitrile of the basic material.

Type II—Medium Hard.

Class 1—Compound utilizing polymerized chloroprene as the basic material.

Class 2—Compound utilizing a copolymer product of butadiene and styrene as the basic material.

Class 3—Compound utilizing a copolymer product of isobutylene and isoprene.

Class 5—Compound utilizing a copolymer product of butadiene and acrylonitrile nitrile of the basic material.

2. APPLICABLE DOCUMENTS

2.1 The following specifications and standards, of the issue in effect on date of invitation for bids, form a part of this specification:

SPECIFICATIONS

FEDERAL

NN-B-591 —Boxes, Fiberboard, Wood-Cleated (for Domestic Shipment).
NN-B-621 —Boxes, Wood, Nailed and Lock Corner.
LLL-B-631 —Boxes; Fiber, Corrugated (for Domestic Shipment).
LLL-B-636 —Boxes, Fiber, Solid (for Domestic Shipment).
PPP-B-601 —Boxes, Wood-Cleated-Plywood.
PPP-B-585 —Boxes; Wood, Wirebound.

FED. SUP. CLASS.
5330, 9320

6.2 Ordering data. - Procurement documents should specify the following:

(a) Title, number and date of this specification.
(b) The grade of phosphor bronze required (see 1.2).
(c) Whether foundry control is required. (see 3 3.1)
(d) Whether nondestructive tests are required (see 3.3.2 and 3.3.3).
(e) Whether pressure tests are required (see 3.4).
(f) Pattern and drawing number.
(g) Whether pattern is to be furnished.
(h) Whether attached test coupons are required (see 4.4.2.3.2).
(i) Level of packing required (see 5.1).
(j) Quantity of castings required.

6.3 Superseding data for Grade C castings. - Grade C castings under MIL-B-16540 (BuOrd) which required castings to be made entirely of scrap should be procured under Federal Specification QQ-L-225, Composition No. 11.

6.4 Radiographic standards for bronze castings are available at the Department of Commerce, Office of Technical Services.

6.5 The contractor may be required to replace castings in which injurious defects are revealed by manufacturing operations performed subsequent to acceptance, without expense to the Government.

Notice. - When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Superseding
MIL-B-16540 (BuOrd)
17 August 1951

MILITARY SPECIFICATION

BRONZE, PHOSPHOR: CASTINGS

This specification has been approved by the Bureau of Naval Weapons, Department of the Navy

1. SCOPE

1.1 Scope. - This specification covers phosphor bronze sand castings containing a controlled lead content.

1.2 Classification. - Phosphor bronze castings covered by this specification shall be of the following grades (see 6.2):

Grade A
Grade B

1.3 Condition. - Phosphor bronze castings shall be furnished in the "as cast" condition.

2. APPLICABLE DOCUMENTS

2.1 The following specifications, standards and publications, of the issue in effect on date of invitation for bids, form a part of this specification to the extent specified herein:

SPECIFICATIONS

FEDERAL
PPP-B-585 - Boxes, Wood, Wirebound.
PPP-B-601 - Boxes, Wood, Cleated-Plywood.
PPP-B-621 - Boxes, Wood, Nailed and Lock-Corner.

MILITARY
MIL-C-132 - Crate, Wood, Open; Maximum Capacity 2,500 Pounds.

STANDARDS

FEDERAL
FED-STD-151 - Metals, Test Methods.

MILITARY
MIL-STD-23 - Nondestructive Testing Symbols.
MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.
MIL-STD-129 - Marking for Shipment and Storage.
MIL-STD-271 - Nondestructive Testing Requirements for Metals.

PUBLICATION

BUREAU OF SHIPS
NAVSHIPS-250-537-1 or 2 - Radiographic Standards for Bronze Castings.

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. - The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated the issue in effect on date of invitation for bids shall apply.

OFFICIAL CLASSIFICATION COMMITTEE

Uniform Freight Classification Rules

(Application for copies should be addressed to the Official Classification Committee, 1 Park Avenue at 33rd Street, New York 16, N. Y.)

3. REQUIREMENTS

3.1 Chemical requirements. - Castings shall conform to the chemical composition requirements of Table I.

Table I. - Chemical requirements.

Grade	Copper	Tin	Zinc	Lead	Iron (max.)	Nickel (max.)	Phosphorus (max.)
	%	%	%	%	%	%	%
A and B	85.0-89.0	7.5-9.0	3.0-5.0	0-1.0	0.25	1.00	0.50

3.1.1 The contractor shall furnish an analysis of each melt of castings showing the percentage of each of the elements specified in Table I, and the percentage of any other elements which have been intentionally added.

3.2 Mechanical properties. - Mechanical properties of these castings, shall conform to those specified in Table II.

Table II. - Mechanical properties.

Grade	Tensile strength (min.)	Elongation in 2 inches (min.)
	Pounds per square inch	Percent
A.....	35,000	18
B.....	30,000	12

3.2.1 The physical properties of Grade B castings will not be determined unless the inspector has reason to doubt that castings are of a quality suitable for the purpose for which they are intended.

3.3 Production control and soundness. -

3.3.1 Foundry control. - When specified (see 6.2), castings shall be produced under foundry control approved by the bureau or agency concerned. Foundry control shall consist of the examination of castings by radiographic or other methods specified by the bureau or agency concerned until the gating,

pouring and other foundry practices have been established to produce castings meeting the quality standards agreed upon by the bureau or agency concerned and the contractor. When the foundry practices have been so established, the practices shall not be changed without demonstrating to the satisfaction of the bureau or agency concerned that the change does not adversely affect the quality of the castings.

3.3.2 Soundness. - When specified (see 6.2), the soundness of the castings shall meet standards agreed upon by the bureau or agency concerned and the manufacturer. The areas of the castings subject to the soundness requirements shall be as specified (see 6.2) and the number and extent of sponginess, blowholes and other defects in such areas shall not be greater than indicated by the standard.

3.3.3 Nondestructive testing. - Radiographic and other nondestructive tests used for foundry control methods and determinations of soundness shall conform to Standard MIL-STD-271. Radiographic examination of castings will not be required unless specified in the contract or order (see 6.2), on the drawings, or in the applicable specifications listed in the contract or order.

3.4 Pressure. - Castings shall meet such pressure requirements as may be specified in the contract or order (see 6.2)

3.5 Dimensions. -

3.5.1 The responsibility for furnishing castings that can be laid out and machined to the finished dimensions, within the specified tolerances, as shown on the blueprints or drawings, and that will conform to such gages as may be specified in individual cases, shall rest with the contractor. Sufficient stock shall be allowed for shrinkage and, where required, for finishing, but castings of excessive size or weight shall not be furnished.

3.5.2 Cast-to-size parts shall conform to dimensions and tolerances specified, and shall not be warped or distorted in such a manner as to adversely affect the appearance or serviceability.

3.6 Repairing of defective castings. -

3.6 1. Castings shall not be welded, plugged, burned in or otherwise repaired without permission from the inspector. Such permission will be given only when the defects are small and do not adversely affect the strength, use, or machinability of the castings.

3.6.2 Each repair shall be encircled with a ring of white paint prior to submission for inspection or shipment.

3.7 Cleaning. - Castings shall be smooth and well cleaned before inspection by sand-blasting, tumbling, chipping, or other process approved by the inspector.

3.8 Identification marking. - When castings are of sufficient size, each casting shall be marked with the following data:

(a) Manufacturer's name or trade-mark.
(b) Heat, melt or lot number.
(c) Pattern or drawing number.

3.8.1 When castings are so small that individual marking is impracticable, castings of the same lot or melt and pattern, shall be wired together or placed in a container, or otherwise segregated and a metal tag containing the data required in 3.8 attached thereto.

3.8.2 Impression stamping. - When impression stamping is used for identification marking, the markings shall be located in areas of low stress as referred to in the blueprint or drawing. Markings should be in locations which will not be machined off.

3.9 Workmanship. - Castings shall be free of injurious blowholes, porosity, hard spots, cracks, and other defects that may be detected by the inspector or are revealed by manufacturing operations subsequent to final acceptance Castings shall be of the highest grade of workmanship and shall be of uniform quality and condition.

4. QUALITY ASSURANCE PROVISIONS

4.1 The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any

other inspection facilities and services acceptable to the Government. Inspection records of the examination and tests shall be kept complete and available to the Government as specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Lot. - A lot shall consist of all the castings of one grade of material produced from the same melt or the same pouring of a furnace, a crucible, or a ladle. When two or more furnace or crucible melts are used to charge a ladle for pouring, the castings produced therefrom shall comprise the lot for sampling purposes.

4.3 Inspection. - Acceptance inspection shall consist of:

(a) Visual examination
(b) Acceptance tests

4.4 Sampling. -

4.4.1 Sampling for Visual examination. - A random sample of castings shall be selected from each lot in accordance with standard MIL-STD-105, Inspection Level III, Acceptable Quality Level (AQL) 1.5 percent defective, and shall be surface inspected under the surveillance of the Government inspector to determine conformance with the cleaning and workmanship requirements of this specification. Lots exceeding the allowable sample defective shall be rejected.

4.4.2 Sampling for Acceptance testing. -

4.4.2.1 Dimensional inspection. - A sample shall be selected at random from each inspection lot in accordance with MIL-STD-105, Inspection Level I, Acceptable Quality Level (AQL) 4.0 percent defective, and inspected for dimensional requirements of this specification to show that they can be properly machined to the required finished dimensions specified.

4.4 2.2 Chemical analysis. - A sample for chemical analysis shall be taken from the first and the last casting of each lot made from the same patterns. The sample for analysis shall consist of not less than five (5) ounces of drillings taken from sound metal below the surface and shall be fine, clean, free from oil, dirt, grit, and foreign matter.

4.4.2.3 Coupons for tension tests. -

4.4.2.3.1 Separately cast coupons (test bars). - Unless otherwise specified, two separately cast test coupons shall be poured from each lot. One shall be cast at the beginning of pouring, and the other at the end of pouring the castings of a lot. The Government inspector shall witness the pouring of the test mold. Test coupons shall be cast in the form and dimensions illustrated by Figure 11, 12a or 12b of Method 211.1 of FED. TEST METHOD STD. No. 151. Separately cast test coupons shall be drawn from the sand only in the presence of the Government inspector, who shall properly mark the coupons for identification. Unless specifically provided for in the contract or order, the chilling of test coupons shall cause the rejection of the material which the coupons represent. The responsibility of furnishing sufficient test specimens shall rest with the contractor.

4.4.2.3.2 Attached coupons. - When specified in the contract or order (see 6.2), or if the manufacturer desires and the procedure is satisfactory to the Government inspector, test coupons shall be attached to the individual castings as follows:

(a) Each casting weighing 250 pounds or more shall have at least one test coupon cast with it, and attached thereto.

(b) If the castings weigh less than 250 pounds, at least one cast test coupon shall be attached to the first and last castings poured in each lot.

4.4.2.3.3 Sample castings. - When the manufacturer so desires, a casting in the lot may be submitted as the test coupon in lieu of test bars or attached cast coupons.

4.4.2.4 Sampling for examination of packing and marking requirements. - Sample castings shall be selected at random

from each lot in accordance with MIL-STD-105, Inspection Level III, Acceptable Quality Level (AQL) 2.5 percent defective, and examined for conformance to (with) the requirements of Section 5.

4.4.2.5 Sampling for non-destructive testing. - When a soundness requirement is specified, sampling shall be accomplished as specified by the bureau or agency concerned (see 6.2).

4.5 Tests. -

4.5.1 Chemical analysis. - The samples, obtained in accordance with paragraph 4.4.2.2, shall be analyzed by Method 111.1 of FED. TEST METHOD STD. No. 151 for conformance with the chemical composition requirements for the specified grade of material. If a sample fails to conform to the requirements of this specification the lot shall be rejected.

4.5.2 Tension test. -

4.5.2.1 Preparation of tensile specimens. - Type R1 tensile specimens shall be prepared from test coupons obtained in accordance with paragraph 4.4.2.3, in conformance to Method 211.1 of FED. TEST METHOD STD. No. 151.

4.5.2.2 Test Procedure. - Tension tests shall be performed in accordance with Method 211.1 of FED. TEST METHOD STD. No. 151, for compliance with the mechanical property requirements of this specification. If any specimen, prepared from a cast test coupon, or a casting, fails to pass the test the casting or lot represented, shall be rejected except as provided in paragraph 4.5.2.3.

4.5.2.3 Retests. - If any tensile specimen, tested under the provisions of 4.5.2.2, contains flaws which result in the failure of the specimen, an additional specimen from the same melt (or from the same casting in the case of coupons attached to castings weighing 250 pounds or more) may, at the discretion of the Government inspector, be selected to replace the defective specimen with one provision. The nature of the flaw, or defect in the discarded specimen, shall be taken into consideration by the inspector before permitting a retest of the material. If additional test coupons are not

available, the replacement specimen may be taken from the body of a casting selected by the inspector from the same lot.

4.5.2.4 Replacement of test specimens. - Test specimens may be discarded and replaced in accordance with the general section of Standard FED-STD-151.

4.5.3 Radiographic examination. - When radiographic examination is required (see 6.2), it shall be conducted in accordance with Standard MIL-STD-271, and the radiographic quality classification which is assigned in accordance with NAVSHIPS-250-537-1 or 2, shall be specified in the applicable specifications, contract or order, or drawings approved by the bureau or agency concerned.

4.5.3.1 The inspector may require radiographic examination of additional areas to investigate the extent of defects revealed by original radiographic examination, by surface inspection, by machining, or by pressure or other tests.

4.5.3.2 Marking of drawings. - When radiographic examination is required, all drawings detailing radiographic examination of castings shall be submitted to the contracting agency for approval. Contractors are required to submit drawings showing the proper radiographic markings, in accordance with Military Standard MIL-STD-23, including the extent, location, and classification assigned. Other pertinent information, such as section thickness, design pressures and temperatures, should be included on the drawings submitted. The type or format of the drawings shall conform to the applicable specification or master drawing system as specified in the contract or order.

5. PREPARATION FOR DELIVERY

5.1 Packing. -

5.1.1 All castings shall be separated by pattern when packed for shipment. Where practicable, shipping containers shall be of uniform size, minimum cube and weight and shall contain the identical number of castings of the same pattern. Containers shall be designed to fit the contents in a compact

manner. Castings shall be adequately blocked, braced, or otherwise secured to prevent their movement within the shipping containers.

5.1.1.1 Finished or polished castings. - Finished or polished castings shall be so packed as to afford adequate protection to the finished surfaces. Where practicable, the castings shall be boxed. Large polished or finished castings, when boxing is not practicable, shall have finished or polished surfaces protected with batten strips.

5.1.1.2 Rough castings. - Unless otherwise specified in the contract or order rough castings not susceptible to damage in shipment may be shipped unpacked or bundled.

5.1.1.3 Castings having projections. - Castings having projections that may be damaged in handling or transit shall be boxed or crated or the projections adequately protected by wood batten strips.

5.1.2 Level A. -

5.1.2.1 Small castings weighing up to 250 pounds each shall be packed in wood cleated plywood (overseas type), nailed wood (class 2) wirebound wood (style 3 for type 2 load) boxes or open crates conforming to Specification PPP-B-601, PPP-B-621, PPP-B-585 and MIL-C-132, respectively at the option of the contractor. Finished or polished castings shall be adequately protected from mechanical damage. Box closures and strapping shall be as specified in the applicable box specification or appendix thereto.

5.1.2.2 Large rough castings weighing more than 250 pounds each require no packing except that, when specified for convenience in handling due to size and shape, the items shall be secured on skids or pallets. Large finished or polished castings having projections or surfaces that may be damaged shall be packed in crates conforming to Specification MIL-C-132 or secured by skids or pallets with the projections adequately protected by wood batten strips.

5.1.3 Level B. -

5.1.3.1 Castings shall be packed as specified for Level A,

except boxes shall be of the domestic type or class.

5.1.4 Level C. -

5.1.4.1 Castings shall be so prepared and shipping containers so constructed as to insure safe delivery by common or other carrier to the point of delivery at the lowest rate, and shall afford maximum protection from the normal hazards of transportation. Containers shall comply with the Uniform Freight Classification Rules or other carrier regulations applicable to the mode of transportation.

5.2 Marking. -

5.2.1 Unless otherwise specified in the contract or order, each bundle, shipping container, and unpacked casting shall be marked with the name of the material; pattern or mold number as specified on the drawings; this specification number and grade; the gross weight and quantity; the name of the contractor, the number of the contract or order.

5.2.2 In addition to the marking specified in 5.2.1 and special markings required in the contract or order, marking of the shipping containers shall be in accordance with Standard MIL-STD-129.

6. NOTES

6.1 Intended use. -

6.1.1 Grade A bronze (1.2) is a leaded phosphor bronze or leaded gun metal which may be used for expansion joints, special pipe fittings, gears, valves, pump pistons and castings, bushings, bearings, and similar applications requiring good strength and resistance to sea-water corrosion.

6.1.2 Grade B bronze (1.2) is a leaded phosphor bronze of the same composition range as Grade A, however, mechanical property requirements are lower and raw material control need not be as precise as for Grade A. Grade B is intended for use where stresses are low and where structural strength is not required.

6.2 Ordering data. - Procurement documents should specify the following:

(a) Title, number and date of this specification.
(b) The grade of phosphor bronze required (see 1.2).
(c) Whether foundry control is required. (see 3 3.1)
(d) Whether nondestructive tests are required (see 3.3.2 and 3.3.3).
(e) Whether pressure tests are required (see 3.4).
(f) Pattern and drawing number.
(g) Whether pattern is to be furnished.
(h) Whether attached test coupons are required (see 4.4.2.3.2).
(i) Level of packing required (see 5.1).
(j) Quantity of castings required.

6.3 Superseding data for Grade C castings. - Grade C castings under MIL-B-16540 (BuOrd) which required castings to be made entirely of scrap should be procured under Federal Specification QQ-L-225, Composition No. 11.

6.4 Radiographic standards for bronze castings are available at the Department of Commerce, Office of Technical Services.

6.5 The contractor may be required to replace castings in which injurious defects are revealed by manufacturing operations performed subsequent to acceptance, without expense to the Government.

Notice. - When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Superseding
MIL-B-16540 (BuOrd)
17 August 1951

MILITARY SPECIFICATION

BRONZE, PHOSPHOR: CASTINGS

This specification has been approved by the Bureau of Naval Weapons, Department of the Navy

1. SCOPE

1.1 Scope. - This specification covers phosphor bronze sand castings containing a controlled lead content.

1.2 Classification. - Phosphor bronze castings covered by this specification shall be of the following grades (see 6.2):

Grade A
Grade B

1.3 Condition. - Phosphor bronze castings shall be furnished in the "as cast" condition.

2. APPLICABLE DOCUMENTS

2.1 The following specifications, standards and publications, of the issue in effect on date of invitation for bids, form a part of this specification to the extent specified herein:

SPECIFICATIONS

FEDERAL
PPP-B-585 - Boxes, Wood, Wirebound.
PPP-B-601 - Boxes, Wood, Cleated-Plywood.
PPP-B-621 - Boxes, Wood, Nailed and Lock-Corner.

MILITARY
MIL-C-132 - Crate, Wood, Open; Maximum Capacity 2,500 Pounds.

MIL-R-114 A
AMENDMENT - 2

NAVAL SUPPLY DEPOT
5801 TABOR AVENUE
PHILADELPHIA, PA. 19120
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
NAVY DEPARTMENT

General Electric Co.
Mr. A. L. Libby,
Product Engineer
2525 Insulator Drive
Baltimore 30, Maryland

RECEIVED
OCT - 5 1966
ENG.

REQUISITION NUMBER (For Local Convenience)

Please self-address the above label. Forward this form to the address shown herein. A window envelope may be used. Your request submitted on this form will speed service. Reorder forms will be enclosed with each shipment.

SPECIFICATIONS AND STANDARDS REQUISITION

IFB, RFQ OR RFP CLOSING DATE

Send one copies of the below listed documents which are listed in the DOD Index of Specifications and Standards.

STANDARDIZATION DOCUMENT SYMBOL	TITLE (From DOD Index of Specifications and Standards)
E — cancelled use QQ-B-637 + QQ-B-639	
MIL-B-994A	"Phosphor-Bronze"
MIL-B-16541	"Brass"
E — cancelled no superseding number	
MIL-B-1644	"Brass"
JAN-R-1149A	"Neoprene"
MIL-B-16540	"Title Unknown"

Ed 9/8

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U.S. 8/13

SIGNATURE A. L. Libby

Fold

DATE August 29, 1966

DD FORM MAR 65 1425 Stock No. 0101-807-1901 REPLACES 4ND-NSD 5200/1 WHICH MAY BE USED
PLATE NO. 14374

STA 1 STA 11 STA 13

TO: COMMANDING OFFICER
U.S. NAVAL SUPPLY DEPOT
5801 TABOR AVENUE
PHILADELPHIA, PA. 19120

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NAVAL SUPPLY DEPOT
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PHILADELPHIA, PA. 19120
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
NAVY DEPARTMENT

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STANDARDIZATION DOCUMENT SYMBOL	TITLE (From DOD Index of Specifications and Standards)
E MIL-B-994A	"Phosphor-Bronze"
MIL-B-16541	"Brass"
E MIL-B-1644	"Brass"
JAN-R-1149A	"Neoprene"
MIL-B-16540	"Title Unknown"

SIGNATURE A. L. Libby
Fold
DATE August 29, 1966

DD FORM MAR 65 1425 Stock No. 0101-807-1901 REPLACES 4ND-NSD 5200/1 WHICH MAY BE USED
PLATE NO. 14374

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TO: COMMANDING OFFICER
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IFB, RFQ OR RFP CLOSING DATE

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E MIL-B-994A	"Phosphor-Bronze"
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JAN-R-1149A	"Neoprene"
MIL-B-16540	"Title Unknown"

cancelled use QQ-B-637 + QQ-B-639

cancelled no superseding number

H.S. 9/13

HPH 9/30

SIGNATURE A. L. Libby
Fold
DATE August 29, 1966

DD FORM MAR 65 1425 Stock No. 0101-807-1901 REPLACES 4ND-NSD 5200/1 WHICH MAY BE USED
PLATE NO. 14374

Ed 9/8

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TO: COMMANDING OFFICER
U.S. NAVAL SUPPLY DEPOT
5801 TABOR AVENUE
PHILADELPHIA, PA. 19120

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DEPARTMENT OF THE NAVY

POSTAGE AND FEES PAID
NAVY DEPARTMENT

OFFICIAL BUSINESS

COMMANDING OFFICER
U.S. ARMY MATERIALS RESEARCH AGENCY
ATTN: AMXMR-TMS
WATERTOWN, MASS. 02171

FOLD

QQ-B-639
APRIL 10, 1961
SUPERSEDING
Fed. Spec. QQ-N-30
October 23, 1957
(See section 6)

FEDERAL SPECIFICATION

BRASS, NAVAL: (FLAT PRODUCTS) PLATE, BAR, SHEET, AND STRIP

This specification was approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers leaded and nonleaded naval-brass flat products (bar, plate, sheet, and strip) with slit, slit and edge-rolled, sheared, sawed, or machined edges.

1.2 Classification.

1.2.1 *Compositions.* The naval brass covered by this specification shall be furnished in one of the compositions shown in table I, as specified (see 6.2). When the composition is not specified, composition 1 shall be furnished.

1.2.2 *Forms, and tempers.* The naval brass covered by this specification shall be furnished in the following forms and tempers, as specified (see 6.2):

Form	*Temper*
Plate, sheet, and bar	Soft Half hard
Strip	Soft Half hard Hard

When temper is not specified, plate, bar, sheet, and strip shall be furnished in the half hard temper.

2. APPLICABLE SPECIFICATIONS, STANDARDS, AND OTHER PUBLICATIONS

2.1 Specifications and standards. The following specifications and standards of the issues in effect on date of invitations for bids form a part of this specification to the extent specified herein.

Federal Standards:

Fed. Std. No. 102—Preservation, Packaging, and Packing Levels.

Fed. Std. No. 123—Marking for Domestic Shipment (Civilian Agencies).

Fed. Std. No. 146—Tolerances for Copper and Copper Base Alloy Mill Products.

Fed. Test Method Std. No. 151—Metals; Test Methods.

(Activities outside the Federal Government may obtain copies of Federal Specifications, Standards, and Handbooks as outlined under General Information in the Index of Federal Specifications, Standards, and Handbooks and at the prices indicated in the Index. The Index, which includes cumulative monthly supplements as issued, is for sale on a subscription basis by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

(Single copies of this specification and other product specifications required by activities outside the Federal Government for bidding purposes are available without charge at the General Services Admin-

570405/61/303

FSC 9530, 9535

istration Regional Offices in Boston, New York, Atlanta, Chicago, Kansas City, Mo., Dallas, Denver, San Francisco, Los Angeles, Seattle, and Washington, D. C.

(Federal Government activities may obtain copies of Federal Specifications, Standards, and Handbooks and the Index of Federal Specifications, Standards, and Handbooks from established distribution points in their agencies.)

Military Specifications:

MIL–C–003993 — Copper and Copper Base Alloy Mill Products; Preparation for Shipment and Storage of.

Military Standards:

MIL–STD–105 — Sampling Procedures and Tables for Inspection by Attributes.

MIL–STD–129—Marking for Shipment and Storage.

MIL–STD–185 — Continuous Identification Marking of Copper and Copper Base Alloys.

(Copies of Military Specifications and Standards, required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 Manufacture. The material shall be manufactured by such hot or cold working followed by such annealing, and straightening as may be required to produce naval brass conforming to the requirements of this specification.

3.1.1 The material shall be furnished in flat, straight lengths unless material in rolls or on reels or bucks is specified in the contract or order.

3.2 Chemical composition.

3.2.1 The material shall conform to the chemical requirements specified in table I.

3.2.2 Analysis shall be made regularly only for the elements specifically mentioned in table I. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that the total of other elements is not in excess of the limits specified.

3.3 Mechanical properties. The material shall conform to the mechanical properties shown in tables II, III, IV and V for the respective tempers.

3.3.1 Where material is required in special forms and tempers other than those specified in tables II, III, IV and V the material shall be defined and specified (see 6.2).

3.4 Internal stresses. Unless otherwise specified in the contract or order, naval brass, except material of soft (finished annealed) temper, shall withstand without cracking the mercurous nitrate test (see 4.6.2.3).

3.5 Heat treatment. Heat treatment, if any, shall be such as to obtain mechanical properties, structure and temper required by this specification. When specified (see 6.2), soft material shall be finish annealed whether previously hot or cold rolled.

3.6 Dimensional tolerances. The following paragraphs of Federal Standard No. 146 shall apply:

Dimension	*Paragraph*
Thickness	1b(1)
Width	1b(2)
Length	1b(3), 1b(4)
Straightness	1b(5)

3.7 Identification marking. Product identification marking for the Air Force, Navy-Bureau of Naval Weps, and Army-Quartermaster Corps shall be in accordance with Military Standard MIL–STD–185. For the other Military agencies, such marking shall be when specified in the contract or order.

3.8 Workmanship. Material shall be uniform in quality and condition, clean, sound, smooth, and free from pipes, slivers, laps, cracks, twists, seams, scale, damaged ends or edges, buckles and other defects which, due to their nature, degree, or extent, detrimentally affect the serviceability for the intended parts. When some characteristic of workmanship is especially important to the serviceability of the intended parts, this information shall be included along with the character of the application of material in the ordering data (see 6.2).

4. SAMPLING, INSPECTION, AND TEST PROCEDURES

4.1 The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the Government. Inspection records of the examination and tests shall be kept complete and available to the Government as specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to the prescribed requirements.

4.2 Lot. Unless otherwise specified in the contract or order, a lot shall consist of 10,000 pounds, or fraction thereof, of material of the same composition, form, size, and temper, submitted for inspection at one time.

4.3 Sampling. Samples taken by the Government inspector for purposes of the tests prescribed in this specification shall be selected in a manner as to represent correctly the material furnished and avoid needless destruction of finished material when samples representative of the material are available from other sources.

4.3.1 *Sampling for chemical analysis.* The number of samples specified in table VI shall be selected from a different piece in each lot. From each sample, not less than 2 ounces of clean millings, drillings, or clippings shall be obtained, placed in separate containers, and forwarded to a laboratory designated by the procuring agency for analysis.

4.3.2 *Sampling for mechanical properties.*

4.3.2.1 *Tension test.* Unless otherwise specified in the contract or order, two tension-test specimens shall be taken from each lot and each shall be selected from a different piece unless the lot consists of one piece in which case one test specimen shall be sufficient.

4.3.2.2 *Mercurous-nitrate test.* Unless otherwise specified in the contract or order, one mercurous-nitrate-test specimen shall be taken from each lot.

4.3.3 *Sampling for visual and dimensional examination.* If the weight of each piece is more than 150 pounds, every piece shall be examined. If the weight of each piece is not over 150 pounds, the inspector shall select sample pieces as specified in 4.3.3.1 and 4.3.3.2.

4.3.3.1 *Visual examination.* From each lot of material composed of pieces weighing 150 pounds or less, a representative sample of material shall be selected in accordance with table VII and shall be visually examined as specified in 4.4.2.1.

4.3.3.2 *Dimensional examination.* From each lot of material composed of pieces weighing 150 pounds or less, a representative sample shall be selected in accordance with table VII and shall be measured as specified in 4.4.2.2. The samples selected for dimensional examination may be the same as those selected for visual examination.

4.3.3.3 When material is furnished in rolls or on reels, or bucks, the sample for examination shall be taken from within 10 feet of the outer end.

4.4 Examination.

4.4.1 *Pieces weighing over 150 pounds.* Each piece in the lot shall be visually examined to determine compliance with the requirements for identification marking (see 3.7) and workmanship (see 3.8) and shall be measured for compliance with the dimensional requirements (see 3.6) of this specification. Straightness of each piece shall be determined as specified in 4.4.3.

4.4.2 *Pieces weighing 150 pounds and under.*

4.4.2.1 *Visual.* Each sample unit selected in accordance with 4.3.3.1 shall be visually examined to determine compliance with the requirements for identification marking (see 3.7) and workmanship (see 3.8).

4.4.2.2 *Dimensional.* Each sample unit selected in accordance with 4.3.4.2 shall be measured to determine compliance with the dimensional requirements (see 3.6) of this specification. Straightness of each sample unit shall be determined as specified in 4.4.3.

4.4.3 *Straightness.* Straightness shall be determined by placing the piece on a level surface so that the arc or departure from straightness is horizontal. The maximum depth of arc shall be measured to the nearest $\frac{1}{32}$ inch by means of a straightedge and a steel scale.

4.4.4 *Preparation for shipment.* Examination of the packing and marking for shipment shall be made for conformance to the requirements of section 5.

4.5 Tests.

4.5.1 *Test specimens.*

4.5.1.1 *Tension-test specimens.* Tension-test specimens for sheet and strip, and for bar and plate up to $\frac{3}{8}$ inch, inclusive, in thickness, shall be machined to the form and dimensions of type F2 of method 211 of Federal Test Method Standard No. 151. Tension test specimens for bar and plate over $\frac{3}{8}$ inch in thickness shall be machined to the form and dimensions of type F1 of method 211 of Federal Test Method Standard No. 151 or in full section. The longitudinal axis of the specimen shall be parallel to the direction of rolling or drawing.

4.5.1.2 *Mercurous-nitrate-test specimens.* Where practicable, the test specimens shall be the full cross-section size of the material approximately 6 inches in length, but shall not exceed 12 inches in length or width. The sawed edges may be smoothed by machining or with a file, but the specimens shall receive no annealing, bending, springing, polishing, or other preparation preliminary to this test.

4.5.2 *Test procedures.*

4.5.2.1 *Chemical analysis.* The samples selected and forwarded in accordance with 4.4.1 shall be analyzed by the wet chemical method in accordance with method 111 of Federal Test Method Standard No. 151 or spectrographic method in accordance with method 112 of Federal Test Method Standard No. 151 to determine conformance with 3.2. A single analysis of a composite sample may be made. In case of dispute, the analysis by the wet method (method 111) shall be the basis for acceptance.

4.5.2.2 *Tension tests.* All tension tests shall be conducted in accordance with method 211 of Federal Test Method Standard No. 151.

4.5.2.2.1 *Yield strength.* The yield strength shall be determined by the extension under load method in accordance with method 211 of Federal Test Method Standard No. 151. The limiting extension shall be 0.005 inch per inch for all specified yield strength values.

4.5.2.3 *Mercurous-nitrate test.* The mercurous-nitrate test shall be conducted in accordance with method 831 of Federal Test Method Standard No. 151.

4.6 Rejection.

4.6.1 *Examination for defects.* Any sample unit having one or more defects shall be rejected. If the number of nonconforming sample units in the sample exceeds the acceptance number specified in table VII for that sample size, the entire lot shall be rejected.

4.6.2 *Test failures.* A lot shall be rejected for failure to meet any of the test requirements when tested in accordance with 4.5

4.7 Retests. Retests shall be permitted in accordance with Federal Test Method Standard No. 151.

5. PREPARATION FOR DELIVERY

5.1 Packing. (See 6.3.)

5.1.1 *Levels A and B.* The material shall be packed in accordance with Military Specification MIL–C–003993.

5.1.2 *Level C.* The products shall be separated by size, composition and temper and packed in accordance with manufacturer's standard practice into containers of the type and size commonly used for the purpose in such a manner as to ensure acceptance by carrier for transportation at the lowest rate applicable and to afford maximum protection from normal hazards of transportation.

5.1.3 *Weight of shipping containers (Air Force only).* For Air Force purposes, the gross weight of shipping containers when specified shall not exceed approximately 250 pounds.

5.2 Marking. (See 6.3.)

5.2.1 *Nonmilitary.* Marking for shipment shall be as specified in Federal Standard No. 123.

5.2.2 *Military.* In addition to any special marking required in the contract or order (see 6.2), marking for shipment shall be in accordance with Military Standard MIL–STD–129.

6. NOTES

6.1 Intended use.

6.1.1 Composition 1 possesses excellent hot working properties with fair machinability. It consists of both alpha and beta grains; is hot workable, but hardens rapidly on cold working.

6.1.2 Composition 2 possesses good hot working properties and good machinability. It consists of both alpha and beta grains; is moderately hot workable but hardens rapidly on cold working. The material is intended for use when free machining is required. Composition 2 is more machinable than composition 1.

6.1.3 Composition 3 possesses good hot working properties, and the machinability is better than composition 1 or 2. It consists of both alpha and beta grains; is moderately hot workable, but hardens rapidly on cold working. The material is intended for use when free machining is required and may be used for the following:

Marine hardware
Applications where a corrosion-resisting material is needed.

6.1.4 Composition 4 is cold workable and has the best resistance to corrosion by salt water of any of the compositions covered by this specification. It consists principally of alpha grains; has limited hot workability. It is intended for use when cold working, bending, forming, or shapping is required.

6.2 Ordering data. Purchasers should exercise any desired options offered herein, and procurement documents should specify the following:

(*a*) Title, number, and date of this specification.

(*b*) Composition, form, temper, and size of the material required (see 1.2).

(*c*) Special forms and tempers required (see 3.3.1).

(*d*) Whether finish annealing of soft material is required (see 3.5).

(*e*) When some characteristic of workmanship is important, the characteristic and the application of the material (see 3.8).

(*f*) Lengths, whether specific or stock lengths with or without ends (see 3.6).

(*g*) When material is to be furnished in rolls, or on reels or bucks (see 3.1.1).

(*h*) Procedure for resubmission of rejected lots.

(*i*) Whether material is to be packed by Level A, B, or C (see 5.1).

(*j*) Maximum gross weight of containers with contents (see 5.1.1).

(*k*) Special marking if required (see 5.2).

6.3 The requirements for item identification marking (see 3.7) and for packing and marking for shipment (see 5.1 and 5.2) specified herein apply to direct shipment for Government activities; and apply also where specified in the contract or order to contracts or orders between the manufacturer and the Government prime contractor.

6.4 Definition of forms.

6.4.1 *Bar.* A bar (as covered by this specification) is a solid rectangular section or one with two plane parallel surfaces and slit, sheared, sawed, or machined edges, up to and including 12 inches in width and over 0.188 inches in thickness.

6.4.2 *Plate.* A plate is a flat rolled product over $\frac{3}{16}$ inch (0.188 inch) in thickness and over 12 inches in width.

6.4.3 *Sheet.* A sheet is a flat rolled product up to and including 0.188 inch in thickness and over 20 inches in width.

6.4.4 *Strip.* A strip (as covered by this specification) is a flat product, other than flat wire, up to and including 0.188 inch in thickness, and furnished with slit, sheared, or slit and edge rolled edges in widths up to 20 inches, inclusive.

6.5 General information.

6.5.1 The thickness of all flat products should be stated in decimals of an inch.

6.5.2 Plate, sheet, and strip should be ordered in as narrow widths as can be used.

6.5.3 For purposes of weight calculations, the weight per cubic inch may be taken as 0.304 pound.

6.5.4 Where no description of the edge of plate, sheet, or strip is specified, the edges furnished will be the finish (slitting, shearing, sawing) most available to the producer and the greatest tolerances shown in Federal Standard No. 146 will be permitted.

6.5.5 When material is ordered in the form of plate, bar, sheet, and strip, it should be understood that these terms refer merely to the general form and dimensions of the material, and do not have any technical significance as to the method of manufacture.

6.5.6 Flat products in rolls are generally more economical than material of the same cross-section in straight or flat lengths.

6.6 Superseding data. This specification supersedes Federal Specification QQ–N–30 dated October 23, 1957 and covers the requirements of Military Specification MIL–B–994C(SHIPS) dated 12 June 1959 (in part). Compositions 1, 2, and 4 of this specification may be used in place of compositions A, B, and C of Military Specification MIL–B–994.

6.7 Federal Specifications do not include all types, classes, or grades, etc., of the commodities indicated by the titles of the specifications, or which are commercially available, but are intended to cover the types, etc., which are suitable for Federal Government requirements.

6.8 Sheet and strip may also be furnished in longer commercial lengths in rolls or on reels or bucks. Plate or bar may be furnished in flat lengths or in rolls.

6.9 Related specification. This specification covers naval brass flat products with slit, slit and edge rolled, sheared, sawed, or machined edges. Federal Specification QQ–B–637 covers rod, bar, wire, shapes, forgings, and flat products with finished edges.

6.9.1 Extruded and forged bars will be covered by a Federal Specification at a later date.

6.10 Definitions of packaging and packing levels are contained in Federal Standard No. 102.

Notice. — When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded, by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

TABLE I.—*Chemical composition*

Composition	Copper	Tin	Lead	Iron (max)	Other elements total (max)	Zinc
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	59.0–62.0	0.50–1.0	[1]0.20	0.10	0.10	Remainder
2	59.0–62.0	.50–1.0	0.4–1.0	.10	.10	Remainder
3	59.0–62.0	.50–1.0	1.3–2.2	.10	.10	Remainder
4	62.0–65.0	.50–1.0	[1]0.20	.10	.10	Remainder

[1]Maximum.

TABLE II.—*Mechanical properties of naval brass, composition 1 only*

Form and temper	Thickness	Tensile strength, minimum	Yield strength, minimum	Elongation in four times thickness, minimum[1]
	Inches	*p.s.i.*	*p.s.i.*	*Percent*
Bar and plate, soft	0.375 and less up to 30 inches wide	52,000	20,000	30
	0.375 and less over 30 inches wide	50,000	20,000	35
	Over 0.375, all widths	50,000	20,000	35
Bar and plate, half-hard	0.375 and less up to 30 inches wide	60,000	35,000	20
	0.375 and less over 30 inches wide	57,000	28,000	30
	Over 0.375, all widths	54,000	25,000	30
Sheet and strip soft	All sizes	52,000	20,000	30
Sheet and strip half-hard	All sizes	60,000	35,000	20
Strip, hard	All sizes	65,000	50,000	10

[1] In any case, a minimum gage length of 1 inch shall be used.

TABLE III.—*Mechanical properties of naval brass, composition 2*

Form and temper	Thickness	Tensile strength, minimum	Yield strength, minimum	Elongation in 4 times thickness, minimum[1]
	Inches	*p.s.i.*	*p.s.i.*	*Percent*
Bar and plate, soft	0.375 and less up to 30 inches wide	52,000	20,000	30
	0.375 and less over 30 inches wide	50,000	20,000	35
	Over 0.375, all widths	50,000	20,000	35
Bar and plate, half-hard	0.375 and less up to 30 inches wide	60,000	35,000	20
	0.375 and less over 30 inches wide	57,000	28,000	30
	Over 0.375, all widths	54,000	25,000	30

[1] In any case, a minimum gage length of 1 inch shall be used.

TABLE IV.—*Mechanical properties of naval brass, composition 3*

Form and temper	Thickness	Tensile strength, minimum	Yield strength, minimum	Elongation in four times thickness minimum[1]
	Inches	*p.s.i.*	*p.s.i.*	*Percent*
Plate, bar, soft	0.375 and less, up to 30 in. wide	52,000	20,000	30
	0.375 and less, over 30 in. wide	50,000	20,000	35
	Over 0.375, all widths	50,000	20,000	35
Plate, bar, half-hard	0.375 and less, up to 30 in. wide	60,000	35,000	20
	0.375 and less, over 30 in. wide	57,000	28,000	30
	Over 0.375, all widths	54,000	25,000	30
Sheet and strip, soft	All sizes	52,000	20,000	30
Sheet and strip, half-hard	All sizes	60,000	35,000	20
Strip, hard	All sizes	65,000	50,000	10

[1] In any case, a minimum gage length of 1 inch shall be used.

TABLE V.—*Mechanical properties of naval brass, composition 4*

Form and temper	Thickness	Tensile strength, minimum	Yield strength, minimum	Elongation in four times thickness, minimum[1]
	Inches	*p.s.i.*	*p.s.i.*	*Percent*
Bar, soft	All sizes	45,000	16,000	30
Bar, half-hard	All sizes	54,000	25,000	20

[1] In any case, a minimum gage length of 1 inch shall be used.

TABLE VI.—*Sampling for chemical analysis*

Pounds of material in lot	Number of samples[1]
Up to 5,000	2
5,001 to 10,000	4

[1] If the number of original bars, billets, or cakes from which the material is processed is less than the number of samples specified, not more than one sample need be taken from each piece.

TABLE VII.—*Sampling for visual and dimensional examination AQL (approx.) = 1.5 percent defective*

Number of pieces in lot	Number of sample units required of
Up to 180	Inspection Level III—MIL–STD–105
181 to 500	Inspection Level II—MIL–STD–105
501 and over	Inspection Level I—MIL–STD–105

CUSTODIANS:
Army—Ord
Navy—Sh
Air Force—MOA.

★ U. S. GOVERNMENT PRINTING OFFICE: 1961

Copies of this specification may be purchased for 10 cents each.

SPECIFICATION ANALYSIS SHEET

Form Approved
Budget Bureau No. 119-R004

INSTRUCTIONS

This sheet is to be filled out by personnel either Government or contractor, involved in the use of the specification in procurement of products for ultimate use by the Department of Defense. This sheet is provided for obtaining information on the use of this specification which will insure that suitable products can be procured with a minimum amount of delay and at the least cost. Comments and the return of this form will be appreciated. Fold on lines on reverse side, staple in corner, and send to preparing activity *(as indicated on reverse hereof)*.

SPECIFICATION

ORGANIZATION *(Of submitter)*

CITY AND STATE

CONTRACT NO.

QUANTITY OF ITEMS PROCURED

DOLLAR AMOUNT
$

MATERIAL PROCURED UNDER A

☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE SPECIFICATION CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?

A. GIVE PARAGRAPH NUMBER AND WORDING.

B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES.

2. COMMENTS ON ANY SPECIFICATION REQUIREMENT CONSIDERED TOO RIGID

3. IS THE SPECIFICATION RESTRICTIVE?

☐ YES ☐ NO IF "YES", IN WHAT WAY?

4. REMARKS *(Attach any pertinent data which may be of use in improving this specification. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity)*

SUBMITTED BY *(Printed or typed name and activity)*

DATE

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QQ-B-637

APRIL 10, 1961

SUPERSEDING
Fed. Spec. QQ–N–35
October 23, 1957
(See section 6)

FEDERAL SPECIFICATION

BRASS, NAVAL: ROD, WIRE, SHAPES, FORGINGS, AND FLAT PRODUCTS WITH FINISHED EDGES (BAR, FLAT WIRE, AND STRIP)

This specification was approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers leaded and nonleaded naval-brass rod, wire, shapes, forgings, and flat products with finished edges (flat wire, strip, and bar).

1.2 Classification.

1.2.1 *Compositions.* The naval brass covered by this specification shall be furnished in the compositions shown in table I. Unless otherwise specified in the contract or order, composition 1 shall be furnished.

1.2.2 *Forms and tempers.* The naval brass covered by this specification shall be furnished in the following forms and tempers, as specified (see 6.2):

Form	*Temper*
Bar and rod	As extruded Soft Cold-heading Half-hard or light annealed Hard
Wire	Soft Cold-heading Half-hard or light annealed Hard
Strip and flat wire	Soft Half-hard Hard
Shapes	As extruded Soft Drawn
Forgings	As forged

When temper is not specified, rod, wire, and flat products (flat wire, strip, and bar) shall be furnished in the half-hard temper. Round rod over ½ inch in diameter may be furnished as standard shafting; round rod over 1 inch in diameter may be furnished for special shafting (see 6.2). Shafting is available with or without piston finish (see 3.6).

2. APPLICABLE SPECIFICATIONS, STANDARDS, AND OTHER PUBLICATIONS

2.1 Specifications and standards. The following specifications and standards of the

570405/61/302

FSC 9525
9530
9535
9540

issues in effect on date of invitations for bids form a part of this specification to the extent specified herein.

Federal Standards:

Fed. Std. No. 102—Preservation, Packaging, and Packing Levels.

Fed. Std. No. 123—Marking for Domestic Shipment (Civilian Agencies)

Fed. Std. No. 146—Tolerances for Copper and Copper Base Alloy Mill Products.

Fed. Test Method Std. No. 151—Metals; Test Methods.

(Activities outside the Federal Government may obtain copies of Federal Specifications, Standards, and Handbooks as outlined under General Information in the Index of Federal Specifications, Standards, and Handbooks and at the prices indicated in the Index. The Index, which includes cumulative monthly supplements as issued, is for sale on a subscription basis by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

(Single copies of this specification and other product specifications required by activities outside the Federal Government for bidding purposes are available without charge at the General Services Administration Regional Offices in Boston, New York, Atlanta, Chicago, Kansas City, Mo., Dallas, Denver, San Francisco, Los Angeles, Seattle, and Washington, D. C.

(Federal Government activities may obtain copies of Federal Specifications, Standards, and Handbooks and the Index of Federal Specifications, Standards, and Handbooks from established distribution points in their agencies.)

Military Specifications:

MIL–C–003993 — Copper and Copper Base Alloy Mill Products; Preparation for Shipment and Storage of.

Military Standards:

MIL–STD–105 — Sampling Procedures and Tables for Inspection by Attributes.

MIL–STD–129—Marking for Shipment and Storage.

MIL–STD–185 — Continuous Identification Marking of Copper and Copper Base Alloys.

(Copies of Military Specifications and Standards, required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 **Manufacture.** The material shall be manufactured by such hot or cold working followed by such annealing and straightening as may be required to produce material meeting the requirements of this specification. The material shall be furnished in straight lengths unless material in rolls, in coils, on reels, or on bucks is specified in the contract or order (see 6.2).

3.2 **Chemical composition.**

3.2.1 The material shall conform to the chemical requirements specified in table I.

3.2.2 Analysis shall be made regularly only for the elements specifically mentioned in table I. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that the total of other elements is not in excess of the limits specified.

3.3 **Mechanical properties.** The material shall conform to the mechanical properties shown in tables II, III, and IV for the respective conditions.

3.3.1 Forgings shall conform to the mechanical properties shown in tables II and III unless other mechanical properties are required in which case the required properties shall be as specified (see 6.2).

3.3.2 Where material is required in special forms and tempers other than those specified in tables II and III, the material shall be defined and specified (see 6.2).

3.4 **Internal stresses.** Unless otherwise specified in the contract or order, naval-brass products in tempers other than soft, as extruded, or cold heading shall withstand without cracking the mercurous nitrate test (see 4.5.2.3).

3.5 **Heat treatment.** Heat treatment, if any, shall be such as to obtain mechanical properties, structure, and temper required by this specification. When specified (see 6.2), soft material shall be finish annealed.

3.6 **Piston finish.** When specified (see 6.2), shafting shall be furnished with piston finish, a special surface produced by grinding.

3.7 **Dimensional tolerances.**

3.7.1 *Forgings.* When dimensional tolerances are not included in the contract or order, open die forgings shall not vary from the specified dimensions by more than plus and minus $\frac{3}{32}$ inch on smooth forgings, or plus and minus $\frac{1}{32}$ inch on rough machined forgings.

3.7.2 *Other forms.* Except where otherwise indicated, the following paragraphs of Federal Standard No. 146 shall apply:

Form and Dimension	*Paragraph*
1. Flat products with finished edges (bar, flat wire, and strip):	
Thickness	2a (1)
Width	2a (2)
Length	2a (3)
Schedule of lengths	2a (4)
Straightness	2a (5)
Standard edge contours	2a (6)
2. Bar and rod, as extruded:	
Diameter or thickness	5a (1)
Straightness and length	5a (2)
3. Rod, cold drawn:	
Diameter	11a (1)[a]
Length	11a (2), 11a (3)
Straightness	11a (4)
4. Rod, hot rolled:	
Diameter	13a (1)
Length and straightness	13a (2)
5. Rod, piston finish:	
Diameter	14a (1)
Length	14a (2)
Straightness	14a (3)
6. Rod, shafting, standard:	
Diameter	14b (1)
Length	14b (2)
Straightness	14b (3)
7. Rod, shafting, special:	
Diameter	14b (1)
Length	14b (2)
Straightness	Tables V and VI[b]
8. Shapes, cold drawn:	
Schedule of lengths	15a (1)
Straightness	15a (3)
9. Shapes, as extruded	16
10. Wire:	
Diameter	24a (1)

[a] When hexagons are ordered for the manufacture of nuts and bolts, tolerances shall be all minus double the specified values.

[b] This specification.

3.7.2.1 *Straightness of special shafting.* When checked at the mill the permissible variations in straightness of rod for special shafting as determined by the departure from straightness (throw in one revolution), shall be shown in table V. All rod for special shafting shall be checked for straightness when supported on rollers at quarter points, and also on rollers at the ends of the rod in lengths as shown in table V.

3.7.2.1.1 *Length of span.* The maximum permissible length of span to be used to determine conformance with table V shall be as shown in table VI.

3.8 **Identification marking.** Product identification marking for the Air Force, Navy-Bureau of Naval Weapons, and Army-Quartermaster Corps shall be in accordance with Military Standard MIL–STD–185. For the other Military agencies, such marking shall be when specified in the contract or order.

3.9 **Workmanship.** Material shall be uniform in quality and condition, clean, sound, smooth, and free from pipes, slivers, laps, cracks, twists, seams, scale, damaged ends or edges, buckles and other defects which, due to their nature, degree, or extent, detrimen-

tally affect the serviceability for the intended parts. When some characteristic of workmanship is especially important to the serviceability of the intended parts, this information shall be included along with the character of the application of material in the ordering data (see 6.2).

4. SAMPLING, INSPECTION, AND TEST PROCEDURES

4.1 The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the Government. Inspection records of the examination and tests shall be kept complete and available to the Government as specified in the contract or order. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 **Lot.** Unless otherwise specified in the contract or order, a lot shall consist of 10,000 pounds, or fraction thereof, of material of the same composition, form, size, and temper, submitted for inspection at one time.

4.3 **Sampling.** Samples taken by the Government inspector for purposes of the tests prescribed in this specification shall be selected in a manner as to represent correctly the material furnished and avoid needless destruction of finished material when samples representative of the material are available from other sources.

4.3.1 *Sampling for chemical analysis.* The number of samples specified in table VII shall be selected from different pieces in each lot. From each sample, not less than 2 ounces of clean millings, drillings, or clippings shall be obtained, placed in separate containers, and forwarded to a laboratory designated by the procuring agency for analysis.

4.3.2 *Sampling for mechanical properties.*

4.3.2.1 *Tension test.* Unless otherwise specified in the contract or order, two tension-test specimens shall be taken from each lot and each shall be selected from a different piece unless the lot consists of one piece in which case one test specimen shall be sufficient.

4.3.2.2 *Mercurous-nitrate test.* Unless otherwise specified in the contract or order, one mercurous-nitrate-test specimen shall be taken from each lot.

4.3.3 *Sampling for visual and dimensional examination.* If the weight of each piece is more than 150 pounds, every piece shall be examined. If the weight of each piece is not over 150 pounds, the inspector shall select sample pieces as specified in 4.3.3.1 and 4.3.3.2.

4.3.3.1 *Visual examination.* From each lot of material composed of pieces weighing 150 pounds or less, a representative sample of material shall be selected in accordance with table VIII and shall be visually examined as specified in 4.4.2.1.

4.3.3.2 *Dimensional examination.* From each lot of material composed of pieces weighing 150 pounds or less, a representative sample shall be selected in accordance with table VIII and shall be measured as specified in 4.4.2.2. The samples selected for dimensional examination may be the same as those selected for visual examination.

4.3.3.3 When material is furnished in coils or rolls or on reels or bucks, the sample for examination shall be taken from within 10 feet of the outer end.

4.4 **Examination.**

4.4.1 *Pieces weighing over 150 pounds.* Each piece in the lot shall be visually examined to determine compliance with the requirements for identification marking (see 3.8) and workmanship (see 3.9) and shall be measured for compliance with the dimensional requirements (see 3.7) of this specification. Straightness of each piece shall be determined as specified in 4.4.3.

4.4.2 *Pieces weighing 150 pounds and under.*

4.4.2.1 *Visual.* Each sample unit selected in accordance with 4.3.3.1 shall be visually examined to determine compliance with the requirements for identification marking (see 3.8) and workmanship (see 3.9).

4.4.2.2 *Dimensional.* Each sample unit selected in accordance with 4.3.3.2 shall be dimensionally examined to determine compliance with the dimensional requirements (see 3.7) of this specification. Straightness of each sample unit shall be determined as specified in 4.4.3.

4.4.3 *Straightness.*

4.4.3.1 *Strip, bar, shapes, and rod except for standard or special shafting.* Straightness shall be determined by placing the piece on a level surface so that the arc or departure from straightness is horizontal. The maximum depth of arc shall be measured to the nearest $\frac{1}{32}$ inch by means of a straight edge and a steel scale.

4.4.3.2 *Rod for standard shafting.* The departure from straightness of rod for standard shafting shall be determined in accordance with paragraph 14b(3). of Federal Standard No. 146.

4.4.3.3 *Rod for special shafting.* Straightness of rod for special shafting shall be determined as specified in 4.4.3.2, except that (1) rod shall be supported as indicated in 3.7.2.1 and (2) the deviation from straightness (throw in one revolution) shall be defined as the difference between the maximum and minimum reading of the dial indicator in one complete revolution of the rod.

4.4.4 *Preparation for shipment.* Examination of the packing and marking for shipment shall be made for conformance with the requirements of section 5.

4.5 **Tests.**

4.5.1 *Test specimens.*

4.5.1.1 *Tension test specimens.*

4.5.1.1.1 *Bar, rod, wire, and flat wire.*

4.5.1.1.1.1 Tension test specimens for bar, rod, wire, and flat wire shall be tested in full size when practicable and the elongation measured in a gage length of four times the diameter of round specimens and of four times the minimum distance across flats of specimens other than round except that the gage length shall be not less than 1 inch. When a machined specimen becomes necessary, enough metal may be removed from the gage section to meet the limitations of the testing machine, or the specimen may be machined to the form and dimensions in accordance with type R1 of method 211 of Federal Test Method Standard No. 151. When a type R1 specimen is used, the elongation shall be measured in a gage length of 2 inches.

4.5.1.1.1.2 For bar and rod up to $1\frac{1}{2}$ inches in diameter or minimum thickness the axis of the test specimen shall coincide with the central axis of the piece. For bar and rod $1\frac{1}{2}$ inches and over in diameter or minimum thickness, when a machined specimen is used, the axis shall be located midway between the center and the surface of the piece.

4.5.1.1.2 *Strip.* Tension test specimens for strip shall be machined to the form and dimensions of type F2 of method 211 of Federal Test Method Standard No. 151. The longitudinal axis of the specimen shall be parallel to the direction of rolling or drawing.

4.5.1.1.3 *Forging and shapes.* The tension test specimen shall be as agreed upon in the contract or order (see 6.2).

4.5.1.2 *Mercurous-nitrate-test specimens.* Where practicable, the test specimens shall be the full cross-section size of the material approximately 6 inches in length, but shall not exceed 12 inches in length or width. The sawed edges may be smoothed by machining or with a file, but the specimens shall receive no annealing, bending, springing, polishing, or other preparation preliminary to this test.

4.5.2 *Test procedures.*

4.5.2.1 *Chemical analysis.* The samples selected and forwarded in accordance with 4.3.2 shall be analyzed by the wet chemical method in accordance with method 111 of Federal Test Method Standard No. 151 or spectrographic method in accordance with method 112 of Federal Test Method Standard No. 151 to determine conformance with 3.2. A single analysis of a composite sample may be made. In case of dispute, the analysis by the wet method (method 111) shall be the basis for acceptance.

4.5.2.2 *Tension tests.* All tension tests shall be conducted in accordance with method 211 of Federal Test Method Standard No. 151.

4.5.2.2.1 *Yield strength.* The yield strength shall be determined by the extension under load method in accordance with method 211 of Federal Test Method Standard No. 151. The limiting extension shall be 0.005 inch per inch for all specified yield-strength values.

4.5.2.3 *Mercurous-nitrate test.* The mercurous-nitrate test shall be conducted in accordance with method 831 of Federal Test Method Standard No. 151.

4.6 Rejection.

4.6.1 *Examination for defects.* Any sample unit having one or more defects shall be rejected. If the number of nonconforming sample units in the sample exceeds the acceptance number specified in table VIII for that sample size, the entire lot shall be rejected.

4.6.2 *Test failures.* A lot shall be rejected for failure to meet any of the test requirements when tested in accordance with 4.5.

4.7 Retests. Retests shall be permitted in accordance with Federal Test Method Standard No. 151.

5. PREPARATION FOR DELIVERY

5.1 Packing (see 6.3).

5.1.1 *Levels A and B.* The material shall be packed in accordance with Military Specification MIL–C–003993.

5.1.2 *Level C.* The products shall be separated by size, composition, and temper and packed in accordance with manufacturer's standard practice into containers of the type and size commonly used for the purpose in such a manner as to ensure acceptance by carrier for transportation at the lowest rate applicable and to afford maximum protection from normal hazards of transportation.

5.2 Marking.

5.2.1 *Nonmilitary.* Marking for shipment shall be as specified in Federal Standard No. 123.

5.2.2 *Military.* In addition to any special marking required in the contract or order (see 6.2), marking for shipment shall be in accordance with Military Standard MIL–STD–129.

6. NOTES

6.1 Intended use.

6.1.1 Composition 1 possesses excellent hot working properties with fair machinability. It consists of both alpha and beta grains; is hot workable, but hardens rapidly on cold working, and is intended for the following uses:

Forgings
Shafting—pump rods, propeller shafting
Condenser bolts

6.1.2 Composition 2 possesses good hot working properties and good machinability. It consists of both alpha and beta grains; is moderately hot workable but hardens rapidly on cold working. The material is intended for use when free machining is required and may be used for the following: Forgings, bolts, studs, nuts (machined), and turnbuckles. Composition 2 is more machinable than composition 1.

6.1.3 Composition 3 possesses good hot working properties, and the machinability is better than composition 1 or 2. It consists of both alpha and beta grains; is moderately hot workable. but hardens rapidly on cold working. The material is intended for use when free machining is required and may be used for the following:

Forgings
Bolts, studs, nuts (machined)
Turnbuckles
Marine hardware
Applications where a corrosion resisting material is needed

6.1.4 Composition 4 is cold workable and has the best resistance to corrosion by salt water of any of the compositions covered by this specification. It consists principally of alpha grains; has limited hot workability. It is intended for use when cold working, bending, forming, or shaping is required and may be used for the following:

Bars, rods and wire—small sizes less than approximately 2.5 inches in diameter or minimum thickness
Bolts, cold headed or rolled thread
Nuts made by the cold upset method

6.1.5 Standard shafting as covered by this specification is suitable for most shafting applications and for applications other than shafting. Special shafting should be used only in limited propulsion shafting applications.

6.2 Ordering data. Purchasers should exercise any desired options offered herein, and procurement documents should specify the following:

(*a*) Title, number, and date of this specification.
(*b*) Composition, form, temper, and size of the material required (see 1.2).
(*c*) Special mechanical properties for forgings (see 3.3.1).
(*d*) Special forms and tempers required (see 3.3.2).
(*e*) Whether finish annealing of soft material is required (see 3.5).
(*f*) When standard or special shafting is required.
(*g*) Dimensions and tolerances for shapes and forgings (see 3.7).
(*h*) When shafting should be furnished with piston finish (see 3.6).
(*i*) When some characteristic of workmanship is important, the characteristic and the application of the material (see 3.9).
(*j*) Lengths, whether specific or stock lengths with or without ends (see 3.7).
(*k*) Whether material is required in straight lengths, coils, rolls, or on reels or bucks (see 3.1).
(*l*) Corners required, if other than square or rounded are desired (see 3.7).
(*m*) When tolerances are required all plus or all minus (see 3.7).
(*n*) Procedure for resubmission of rejected lots.
(*o*) Special test specimens for forgings and shapes.
(*p*) When saddles are required for packing shafting.
(*q*) Whether material is to be packed by level A, B, or C (see 5.1).

(*r*) Maximum gross weight of containers with contents (see 5.1.1).
(*s*) Special marking if required (see 5.2).
(*t*) When desired, requirements for surface finish.

6.3 The requirements for item identification marking (see 3.8) and for packing and marking for shipment (see 5.1 and 5.2) specified herein apply to direct shipment for Government activities and apply also, where specified, to contracts or orders between the manufacturer and the government prime contractor.

6.4 Definition of forms.

6.4.1 *Bar.* A bar is a solid rectangular section, or one with plane parallel surfaces and round or other simple regularly shaped edges, up to and including 12 inches in width and over 0.188 inch in thickness.

6.4.2 *Rod.* A rod is a round, hexagonal, or octagonal solid section furnished in straight lengths.

6.4.3 *Shape.* A shape is a solid section other than rectangular, square, or standard rod and wire sections. Shapes include such forms as angles, channels, bars, and material in bar form with other than square corners, rounded corners, rounded edges, or full rounded edges.

6.4.4 *Flat wire.* Flat wire is a flat product up to and including 0.188 inch in thickness and up to and including 1¼ inch width with all surfaces rolled or drawn without previous slitting, shearing, or sawing. It may be furnished in straight lengths, or on spools, reels, or bucks.

6.4.5 *Strip.* A strip (as covered by this specification) is a flat product, other than flat wire, up to and including 0.188 inch in thickness and generally furnished with finished drawn or rolled edges in widths over 1¼ inch to 12 inch inclusive.

6.4.6 *Wire.* A solid section, other than strip, furnished in coils, or on spools, reels, or bucks.

6.5 General information.

6.5.1 The thickness of all flat products should be stated in decimals of an inch.

6.5.2 Strip should be ordered in as narrow widths as can be used.

6.5.3 For purposes of weight calculations, the weight per cubic inch may be taken as 0.304 pound.

6.5.4 Flat products in rolls are generally more economical than material of the same cross-section in straight or flat lengths.

6.6 Superseding data. This specification supersedes Federal Specification QQ–N–35 dated October 23, 1957 and covers the requirements of Military Specification MIL–B–994C (Ships) dated June 12, 1959 (in part). Compositions 1, 2, and 4 of this specification may be used in place of compositions A, B, and C of MIL–B–994.

6.7 Federal specifications do not include all types, classes, or grades, etc., of the commodities indicated by the titles of the specifications, or which are commercially available, but are intended to cover the types, etc., which are suitable for Federal Government requirements.

6.8 Flat wire and strip may also be furnished in longer commercial lengths as follows, when specified.

Flat wire—on spools, reels or bucks.
Strip—on bucks or in rolls.

6.9 Related specification. This specification covers naval brass rod, bar, wire, shapes, forgings, and flat products with finished edges. Federal Specification QQ–B–639 covers flat products with slit, slit and edge rolled, sheared, sawed, or machined edges.

6.10 The chemical composition and the mechanical properties of the composition covered by this specification are similar to the chemical composition and mechanical properties of the ASTM alloys as given below:

Composition	*ASTM Alloy*
1	Alloy A, B21
2	Alloy B, B21
3	Alloy C, B21
4	None

6.11 Definitions of packaging and packing levels are contained in Federal Standard No. 102.

Notice. — When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded, by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

TABLE I.—*Chemical composition*

Composition	Copper	Tin	Lead	Iron (maximum)	Other elements total (maximum)	Zinc
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	59.0–62.0	0.5–1.0	[1]0.20	0.10	0.10	Rem.
2	59.0–62.0	0.5–1.0	0.4–1.0	.10	.10	Rem.
3	59.0–62.0	0.5–1.0	1.3–2.2	.10	.10	Rem.
4	62.0–65.0	0.5–1.0	[1]0.20	.10	.10	Rem.

[1] Maximum

TABLE II.—*Mechanical properties of Naval brass composition 1 only*

Form and temper	Size (diameter or distance between parallel faces unless otherwise stated)	Tensile strength, minimum	Yield strength, minimum	Elongation in four times diameter or thickness[1] minimum
	Inches	*p.s.i.*	*p.s.i.*	*Percent*
Bar, rod, and shapes, as extruded	All sizes	52,000	20,000	30
Bar, rod, and wire, soft	1.000 and under	54,000	20,000	30
	Over 1.000 to 2.000, incl.	52,000	20,000	30
	Over 2.000	50,000	20,000	30
Bar, rod, and wire, half hard or light annealed	0.500 and under	60,000	27,000	22
	Over 0.500 to 1.000, incl.	60,000	27,000	25
	Over 1.000 to 2.000, incl.	58,000	26,000	25
	Over 2.000 to 3.000, incl.	54,000	25,000	25
	Over 3.000 to 4.000, incl.	54,000	22,000	27
	Over 4.000	54,000	22,000	30
Bar, rod, and wire, hard	1.000 and under	67,000	45,000	13
	Over 1.000 to 2.000, incl.	62,000	37,000	18
Flat wire and strip, soft	All sizes	52,000	20,000	30
Flat wire and strip, half-hard	All sizes	60,000	35,000	20
Flat wire and strip, hard	All sizes	65,000	50,000	10
Forgings	4 pounds and less	52,000	22,000	30
	Over 4 pounds	50,000	20,000	30
Shapes, soft	All sizes	52,000	20,000	30
Shapes, extruded and drawn[2]	All sizes	58,000	25,000	20

[1] In any case, a minimum gage length of 1 inch shall be used.
[2] Shapes, extruded and drawn, do not apply to hollow shapes or those of continuous periphery.

TABLE III.—*Mechanical properties of naval-brass compositions 2 and 3*

Form and temper	Size (diameter or distance between parallel faces)	Tensile strength, minimum	Yield strength, minimum	Elongation in four times diameter or thickness[1]	
				Comp. 2	Comp. 3
	Inches	*p.s.i.*	*p.s.i.*	*Percent*	*Percent*
Bar, rod and shapes as extruded	All sizes	52,000	20,000	25	20
Bar, rod, and wire, soft	1.000 and under	54,000	20,000	25	20
	Over 1.000 to 2.000, incl.	52,000	20,000	25	20
	Over 2.000	50,000	20,000	25	20
Bar, rod, and wire, half-hard or light annealed	1.500 and under	60,000	27,000	18	12
	Over 1.000 to 2.000, incl.	58,000	26,000	20	20
	Over 2.000 to 3.000, incl.	54,000	25,000	20	20
	Over 3.000 to 4.000, incl.	54,000	22,000	20	20
	Over 4.000	54,000	22,000	25	20
Bar, rod, and wire, hard	1.000 and under	67,000	45,000	11	10
	Over 1.000 to 2.500, incl.	62,000	37,000	15	13
	Over 2.500 to 3.500, incl.	54,000	25,000	20	20
	Over 3.500	54,000	22,000	25	20
Shapes, soft	All sizes	52,000	20,000	25	20
Shapes, extruded and drawn[2]	All sizes	58,000	25,000	15	15
Forgings	4 pounds and less	52,000	22,000	25	20

[1] In any case, a minimum gage length of 1 inch shall be used.
[2] Shapes, extruded and drawn, do not apply to hollow shapes or those of continuous periphery.

TABLE IV.—*Mechanical properties of naval brass composition 4*

Form and temper	Size (diameter or distance between parallel faces)	Tensile strength, minimum	Yield strength, minimum	Elongation in four times thickness or diameter[1] minimum
	Inches	*p.s.i.*	*p.s.i.*	*percent*
Bar, rod and shapes as extruded	All sizes	50,000	20, 000	30
Bar, rod, and wire, soft	All sizes	48,000	16,000	30
Rod and wire, for cold heading and cold forming	All sizes	48,000	18,000	22
Bar, rod, and wire, half-hard or light annealed	0.500 and under	58,000	27,000	22
	Over 0.500 to 1.000, incl.	56,000	27,000	25
	Over 1.000 to 2.000, incl.	54,000	26,000	25
	Over 2.000 to 3.000, incl.	52,000	25,000	27
	Over 3.000 to 4.000, incl.	50,000	22,000	30
	Over 4.000	50,000	20,000	30
Bar, rod, and wire, hard	0.500 and under	64,000	40,000	13
	Over 0.500 to 1.000, incl.	62,000	38,000	13
	Over 1.000 to 2.000, incl.	58,000	34,000	18

[1] In any case, a minimum gage length of 1 inch shall be used.

TABLE V.—*Permissible variations in straightness of rod for special shafting*

Span	Rod supported at ends			Rod supported at quarter points		
	At 1st quarter point	At center	At 3rd quarter point	At 1st end	At center	At 2nd end
Feet	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
6	0.004	0.006	0.004	---	---	---
8	.006	.010	.006	0.006	0.004	0.006
10	.012	.016	.012	.012	.006	.012
12	.018	.024	.018	.018	.006	.018
14	.024	.032	.024	.024	.008	.024
16	.030	.042	.030	.030	.012	.030
18	.040	.054	.040	.040	.014	.040
20	.048	.066	.048	.048	.016	.048
22	---	---	---	.060	.020	.060
24	---	---	---	.072	.024	.072
26	---	---	---	.084	.028	.084
28	---	---	---	.096	.032	.096
30	---	---	---	.112	.038	.112

TABLE VI.—*Maximum permissible length of span for the determination of conformance with table V*

Diameter of rod	Allowable length of rod when supported at the ends[1]
Inches	*Feet*
1	9
1⅛	10
1¼	10
1⅜	11
1½	11
1⅝	12
1¾	12
2	13
2¼	14
2⅜	14
2½	15
2¾	15
3	16
3½	17
4	19
4½	20
5	21

[1] With the rod supported at the first and third quarter points, the allowable length shall be twice the value given.

TABLE VII.—*Sampling for chemical analysis*

Pounds of material in lot	Number of samples[1]
Up to 5,000	2
5,001 to 10,000	4

[1] If the number of original bars, billets, or cakes from which the material is processed is less than the number of samples specified, not more than one sample need be taken from each piece.

TABLE VIII.—*Sampling for visual and dimensional examination AQL (approx.) = 1.5 percent defective*

Number of pieces in lot	Number of sample units required of
Up to 180	Inspection Level III—MIL–STD–105
181 to 500	Inspection Level II—MIL–STD–105
501 and over	Inspection Level I—MIL–STD–105

CUSTODIANS:
Army—Ord
Navy—Sh
Air Force—MOA.

★ U. S. GOVERNMENT PRINTING OFFICE: 1951

Copies of this specification may be purchased for 10 cents each.

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ORGANIZATION *(Of submitter)*

CITY AND STATE

CONTRACT NO.

QUANTITY OF ITEMS PROCURED

DOLLAR AMOUNT
$

MATERIAL PROCURED UNDER A

☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE SPECIFICATION CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?

A. GIVE PARAGRAPH NUMBER AND WORDING.

B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES.

2. COMMENTS ON ANY SPECIFICATION REQUIREMENT CONSIDERED TOO RIGID

3. IS THE SPECIFICATION RESTRICTIVE?

☐ YES ☐ NO IF "YES", IN WHAT WAY?

4. REMARKS *(Attach any pertinent data which may be of use in improving this specification. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity)*

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ORGANIZATION | CITY AND STATE

CONTRACT NO. | QUANTITY OF ITEMS PROCURED | DOLLAR AMOUNT $

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Maintaining SCIENTIFIC TOLERANCES *by* INSPECTION

By WILLIAM B. RICE

DEPARTMENT OF STATISTICS AND REPORTS, PLOMB TOOL COMPANY, LOS ANGELES, CALIF.

FOLLOWING in the footsteps of Shewhart (1),[1] Simon (2), Wilks (3), and others, the author suggested in a recent article (4) that design tolerances for manufactured products be determined from factual data, analyzed statistically as to:

(*a*) The characteristics required by users of the products.

(*b*) The characteristics of the manufacturing process by which the products are made.

When it has been determined that the process is capable of producing, at a satisfactory cost, a product which meets consumer requirements, the next problem is how to hold the process at the desired level. This is basically an inspection problem.

Before the manufacturer's inspection can succeed in maintaining the characteristics he wants in his product, three requirements must be met:

1 The manufacturer needs to know that his process can be depended upon, that no unpredictable changes occur during production, that he is actually producing what he intends to produce. These requirements can be met only with a statistically controlled process, as evidenced by the use of quality-control charts (5).

2 The manufacturer needs to know that his specifications are practical and profitable, that they will meet consumer demands at a profit to him. A method of meeting this requirement was suggested in the author's previous article (4).

3 The manufacturer needs to know that his inspection procedures are adequate, that from his inspection records he can draw sound and correct conclusions about that part of his product which he does not inspect, in order to be sure that the first and second requirements are being met.

This third requirement is the subject of the present article.

CONCEPTS INVOLVED

Before proceeding with the discussion it seems advisable to give a brief summary of the concepts involved in setting tolerances by statistical methods:

1 Recognition that all things vary and that variability can best be analyzed with statistical techniques. Tolerances should therefore be expressed in statistical terms, such as $\bar{X} \pm t\sigma$, rather than in absolute dimensions such as A, B.

2 Recognition that, in general, no tolerance limits can be set which will always include all pieces produced; that is, tolerances should be considered as probability limits, not absolute limits.

3 Recognition that tolerance limits vary in strictness, depending upon the seriousness of out-of-tolerance work, that more out-of-tolerance work can be permitted for minor defects than for major defects. In other words, specifications may be written $\bar{X} + t\sigma$, $\bar{X} - t'\sigma$, the value of t being different for each type of defect; larger for more serious than for less serious defects.

In the author's previous article (4), an illustration was given of the torque required for an open-end wrench; a "consumer" tolerance of 1500 in-lb, a process capable of holding 2100 in-lb and a design specification of 2000 in-lb, which the process was able to meet and which gave a 33⅓ per cent margin of safety over the consumer requirement.

How should inspection be set up so as to be sure that the wrenches produced are satisfactory? Several possible methods present themselves. Torque tests could be made on every wrench, i.e., 100 per cent inspection; however, such inspection would be not only expensive but also inefficient because unnecessary. With a 33⅓ per cent margin of safety, an occasional failure below the 2000-in-lb specification could be permitted.

Alternatively, sample torque tests could be performed. Assuming lots of 5000 wrenches, with 0.5 per cent defective permitted, the sample would have to be about 1000 pieces out of each lot (6). Such an inspection plan would still be quite expensive and would not give much information except to assure the desired quality level.

Yet another method would be to apply destructive torque tests to a small sample from each lot of 5000 wrenches, the torque being increased until the wrench broke. In this case the sample would have to be quite small for reasons of economy, so small in fact that sound judgments about the remaining wrenches could not be made on the basis of the single small sample.

CONTROL-CHART INSPECTION

All the objectionable features of the methods just proposed can be avoided, and practical certainty of a satisfactory product can be had by adapting the control-chart technique in somewhat the way used by Lieut. Col. Simon at the Aberdeen Proving Ground (2).

Five wrenches from each 1000 can be tested destructively and the readings recorded on control charts (5). As long as the process remains in "statistical control" at a satisfactory level (say, between 2100 and 2400 in-lb), only a small sample of 50 to 100 need be nondestructively tested for conformance to specifications in order to assure satisfactory outgoing quality.

Control charts can simplify and economize inspection procedures in this way because, with a "controlled" process, the manufacturer can be sure that his production methods are turning out a product with consistent characteristics, i.e., with only chance variations; he can be certain that no unknown or unexpected accidents are producing erratic and unpredictable results. Therefore, with this confidence and with the facts revealed by his control charts, he can safely depend upon a mere check test at final inspection.

The design specifications for this wrench should be so written as to provide for the correct inspection procedure. For instance, the upper tolerance limit could be omitted, but the

[1] Numbers in parentheses refer to the Bibliography at the end of the paper.

lower tolerance limit written in the form $\bar{X} - 3\sigma > 2000$ in-lb. The inspection specifications should call for control charts in approved form to insure meeting of specifications by the manufacturing process, and a torque check test of, say, 50 pieces out of each lot at final inspection to insure acceptable outgoing quality.

AN ASSEMBLY PROBLEM

A more complex situation arises when assemblies of two or more parts are involved. In the author's previous article (4), an illustration was given of an extension-and-socket assembly where the minimum clearance between the parts was required to be 0.004 in. and the maximum clearance 0.015 in. After analysis of the manufacturing process, design specifications were set up which called for female square (socket) tolerances of 0.515–0.511 in. and male square (extension) tolerances of 0.507–0.502 in.

The purpose of these tolerances was to make sure that the mechanics who used the tools would get a clearance above the maximum or below the minimum only about one time in a thousand assemblies. In other words, these tolerances were not absolute limits in the usual sense but probability limits. Totals of 3 per cent oversize and 3 per cent undersize parts were permitted by the specifications on each component; a probability of 0.03 on the female and of 0.03 on the male becomes $0.03 \times 0.03 = 0.001$ for the two parts when assembled.

The purpose of inspection here is not to assure a perfect product, but to assure an acceptable product; in this case not more than 3 per cent too large and 3 per cent too small. Detail or 100 per cent inspection is therefore not called for; some sampling scheme is more appropriate.

In deciding on the best sampling plan to use, two basic considerations should be kept in mind; (*a*) how to interpret the quality requirements implicit in the specifications; and (*b*) how to get the desired inspection results most economically.

As to interpretation, does the 3 per cent limit mean that no single lot worse than 3 per cent will ever be accepted? Or that only one lot in ten (or some other proportion) will be accepted if worse than 3 per cent? Or does it mean that over a long period of time the average quality must be not worse than 3 per cent?

In general, if the product is manufactured by a more or less continuous process, the long-term average interpretation may be used. Assuming an average lot size of 5000, a process average of 3.0 per cent and a desired long-term quality limit of 3 per cent, the Dodge-Romig tables[2] give the following sample sizes for most economical inspection cost:

Taking a single sample, inspect 210 pieces from each lot, allowing 10 or less defectives; detail all lots failing to pass the test. Taking a double sample, inspect 215 in the first sample, allowing 7 or less defectives; if more than 7 defectives are found in the first sample, inspect 390 more, allowing 27 defectives in all 605 pieces inspected. Detail all lots which fail the second sample.

Many other solutions of this problem are possible, depending upon the assumptions made and the theoretical approach used. For instance, if the process is known to be in a state of statistical control, the sample size and the cost of inspection may be greatly reduced. The Army Ordnance tables[3] recognize this fact.

If the sockets in this illustration are manufactured by an intermittent process, the lot-by-lot quality interpretation may be used. For the circumstances in this illustration the Dodge-Romig tables are not adapted, but other approaches are possible. Simon's I_0 charts (2) show that the desired protection can be obtained by accepting or rejecting on the basis of a sample size of approximately 130, allowing not more than one defect in the sample; only one lot in 10 will then be accepted with a quality worse than 3 per cent. Almost the same solution is offered by Working (7).

Neither of the interpretations so far discussed, nor any of the sampling plans proposed, are reasonable, however, because they set upper bounds of acceptability at the level of 3 per cent while by implication 3 per cent is expected to be the "average" quality produced by the process. That 3 per cent is the expected average quality is clear from the fact that the tolerance limits were set at $\bar{X} \pm 1.86\sigma$. If the frequency distributions were always exactly centered and exactly normal, exactly 3.14 . . . per cent of the pieces would fall outside on each tail of the curve. But the ideal conditions would never be met exactly—merely approximated over a period of time. A percentage of 3.14 therefore should be considered an average result rather than an extreme result.

The most satisfactory method of maintaining a desired average is by use of a control chart. Letting $\bar{p}$ be the process average actually obtained in manufacturing operations, and letting p' be the desired quality level, $\bar{p}$ should be equal to or less than p'.

In order to select the sample size desired, a practical criterion is to inspect a large enough number of pieces so that at least one defective will be found 9 times out of 10 in a 3 per cent defective lot. Simon's $0.9 = I_0$ chart (2) can be used for this purpose, yielding 130 as the sample size. Control limits can then be set at

$$p' \pm 3\sqrt{\frac{p'(1-p')}{N}}$$

In the present sample, $p' = 3.0$ per cent, $N = 130$, and the limits are 7.5 per cent and 0 per cent. As long as the per cent defective falls below 7.5 per cent with a sample of 130, the product can be considered as acceptable, that is, as conforming to specifications.

It may be convenient, if a constant sample of 130 pieces is inspected from every lot presented, to convert these percentages to $p'n$ or acceptable number of defectives permitted in each sample. A percentage of 7.5 of 130 is 9.75, that is, the lot will be accepted if 9 or fewer defective pieces are found in the sample, rejected if 10 or more are found. In addition, a series of seven or more lots above the average 3 per cent level should be cause for suspicion that the process is not satisfactory; in this case $\bar{p}$ should be recalculated, and inspection tightened up. If at any time a point falls above the upper control limit of 7.5 per cent, detail inspection would be necessary and investigation should be undertaken at once to discover the cause of the bad work.

Since the lower limit is 0 per cent, no point can fall below it; but 7 or more consecutive points below the 3 per cent average could be taken to mean a probable improvement in the process and would warrant reduced inspection. An investigation should be made to determine the cause of improvement, with the aim of incorporating it as a permanent manufacturing procedure.

A further reduction in inspection should be permissible if 20 or more successive points are in control. In that case the Ordnance procedure could be followed. A sample size of 26 (one fifth as large as the regular sample) could be taken from each lot, provided (*a*) that the per cent defective in any reduced sample falls within control limits recalculated by the formula $p' \pm 3\sqrt{\frac{p'(1-p')}{N}}$, where N is 26; and (*b*) that the total number of defectives in any five small samples shall meet the requirements for any one large sample. In the present illustration with $p' = 3.0$ per cent, not more than 2 defectives would be

[2] Reference (6), Tables SA-3.0 and DA-3.0. Certain other assumptions, not mentioned here, are stated in the reference, which should be studied for further information.

[3] These are the tables used by the Ordnance Department, U. S. Army. They have not been published for general use.

permitted in any small sample of 26; and not more than a total of 9 in any five successive small samples.

Further refinements can be made in this type of inspection procedure, but perhaps the illustrations given will suffice to indicate one statistical approach to inspection problems. Much more could be said as to standards, gages, personnel, and other aspects of inspection, but these are less concerned with statistics than with engineering, design, and organization. But on the important matter of how much to inspect, statistical methods offer almost the only scientific solution.

It has been impossible to mention many of the basic implications of statistically designed inspection methods, i.e., randomness, consumer's risk, reliability, a priori and posteriori probability, and others. These are ably discussed in the various references, particularly by Dodge and Romig (6). Those who wish to pursue the subject further are advised to study the authorities carefully.

STATISTICAL SPECIFICATIONS

The application of "control-chart inspection" to statistically determined process and design specifications is graphically illustrated in Fig. 1. There a general grouping of all types of defects for any manufacturing process is proposed, with statistical, that is, probability, definitions of the critical, major and minor classifications. The suggested scheme is outlined and illustrated as follows:

Based upon facts gathered and interpreted as proposed in the author's previous article (4), the engineering department can set up scientific tolerances along the following lines:

Let S represent the design tolerances, and P_t the probability of a piece falling outside $\overline{X} \pm t\sigma$

If $\overline{X} = \dfrac{A+B}{2}$ and $t = \dfrac{A-B}{2}$, this becomes

$$S = \overline{X} \pm t\sigma.$$

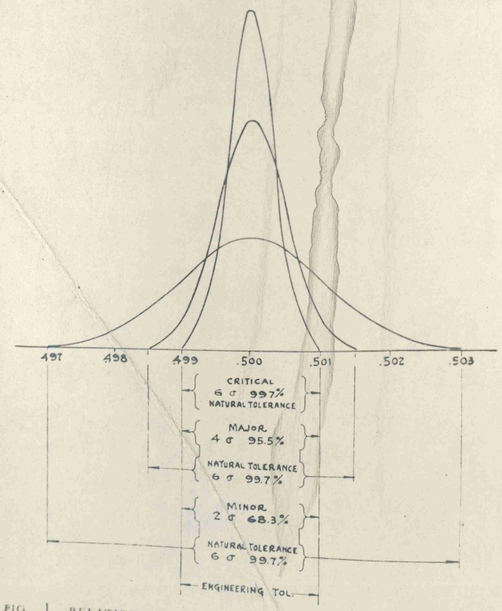

FIG. 1 RELATIONSHIP BETWEEN ENGINEERING AND NATURAL TOLERANCES FOR CRITICAL, AND MAJOR AND MINOR DEFECTS

Then, having as prerequisites (*a*) a statistically controlled process, and (*b*) a normal frequency distribution:

For a critical defect let $t = 3$ and $P_t = 0.003$ approximately
For a major defect let $t = 2$ and $P_t = 0.05$ approximately
For a minor defect let $t = 1$ and $P_t = 0.33$ approximately

As an illustration, suppose the tolerances were 0.501, 0.499. Then

$$\overline{X} = \frac{0.501 + 0.499}{2} = 0.500, \text{ and } t = \frac{0.501 - 0.499}{2} = 0.001$$

For a critical defect $t = 3$, therefore $3\sigma = 0.001$, and not more than 0.3 per cent out-of-tolerance pieces would be permitted.

For a major defect $t = 2$, therefore $2\sigma = 0.001$, and not more than 5 per cent out-of-tolerance pieces would be permitted.

For a minor defect $t = 1$, therefore $1\sigma = 0.001$, and not more than 33 per cent bad parts would be permitted.

Diagrammatically, Fig. 1 clarifies this approach to the problem.

In Fig. 1 the three curves illustrate the actual frequency distributions which would be typical of the three types of defects. The tall narrow curve is that which the process must produce if the defect is critical and blueprint tolerances are strictly adhered to. Similarly, the middle curve shows how much more leeway can be given production if the defect is a major one; and the low wide curve visualizes the process limits permissible for a minor defect. Note that the same gages and the same blueprint tolerances can be used for all three, simply by varying the percentage of out-of-tolerance work permitted.

In the socket and extension problem discussed, the tolerances were established at $\overline{X} \pm 1.86\sigma$, and 3 per cent out-of-tolerance pieces were permitted on each side of the curve. For purposes of standardization this could be modified to $\overline{X} \pm 2\sigma$, making it a major defect according to the definition proposed here, and allowing not more than $2^1/_2$ per cent to be too large and $2^1/_2$ per cent to be too small.[4]

Then at inspection the critical defects should require 100 per cent or detail inspection, the others, various degrees of sampling inspection. In each case inspection records kept in the form of control charts would give assurance that the process is satisfactory and that the required standard is being met. If the chart is not in control at a satisfactory level, action can be taken to improve the process, to revise specifications, or otherwise to get engineering, production, and inspection ideas to meet on common ground.

Such a meeting of minds will go far in bringing the members of the business team into harmony, all working toward a common goal. And this community of purpose will benefit labor, management, and investors alike.

[4] It will frequently be found in practice that one tolerance limit is critical, the other major or minor. The design and inspection problems involved in unequally spaced tolerance limits are, however, too extensive to be discussed in this article.

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4 "Setting Tolerances Scientifically," by W. B. Rice, MECHANICAL ENGINEERING, vol. 66, 1944, pp. 801–803.

5 "Control Chart Method of Controlling Quality During Production," see American Standards Association, Z1.3, 1942.

6 "Sampling Inspection Tables," by H. F. Dodge and H. G. Romig, John Wiley & Sons, Inc., New York, N. Y., 1944. Reference is to table SL-0.5, lot size 5000, process average 0.051–0.100.

7 Charts in "Guide to the Use of the Binomial and Poisson Distributions," by Holbrook Working, Stanford University Press, 1943.

D. PREPARATION OF SLURRY

1. A suspension shall be prepared which has the following composition:

20 grams of CAB-O-SIL* - TURNER USES HS-5
1 gram of PHOTO-Flo 600
1000 grams of water

The conductivity of this suspension shall be adjusted by adding a suitable amount of sodium chloride (NaCl) to obtain the conductivity level desired.

A sufficient amount of this suspension shall be prepared for dip coating of insulators.

2. Four reference levels of conductivity shall be used in the tests. The conductivity of the suspension shall be obtained by adding 2.5, 5.0, 10.0, and 20.0 grams of salt (NaCl) to the above mixture.

E. COATING OF THE TEST SPECIMEN

For polluting the insulators, the above mixture of the desired conductivity level shall be used. Insulators shall be dipped in the mixture with the axis of the insulator in a horizontal position. Insulators shall be handled by the hardware to avoid injury to the coated surfaces. After the insulator has been coated, it shall be mounted for the test and aperiod of 5 minutes should be allowed for the dripping to stop and the coating to stabilize.

F. CONDUCTIVITY MEASUREMENTS

The degree of contamination on the insulator surface shall be measured in each of the following ways:

1. The amount of salt and binder in the coating liquid shall be specified.

2. Measurements shall be made of the slurry to determine its condictivity. A sample of the slurry shall be taken and filtered. The clarified liquid shall be measured using a conductivity bridge. The amount of salt in solution can then be determined by comparison with standard curves.

3. Before applying high voltage to the test specimen, a low voltage is to be applied and the leakage current measured. The A.C. measuring

*CAB-O-SIL is a trade name and is a pure form of SiO_2. This is a pyrogenic silica having an extremely small particle size. It can be obtained from: Hampden Color and Chemical Co., 126 Memorial Drive, Springfield, Mass.

MEMORANDUM

August 21, 1969

PROCEDURE FOR CONDUCTING CONTAMINATION TESTS ON SUSPENSION INSULATORS

A. GENERAL

At the present time there is a great need for an artificial contamination test for high voltage suspension insulators for use in polluted areas. In such areas the behavior of suspension insulators is frequently the limiting factor in determining the size and type of insulator to be used.

B. WITHSTAND VOLTAGE TEST

The object of this test is to determine the maximum withstand voltage at a given reference layer conductivity. A series of testsshall be conducted as prescribed in this memorandum on an insulator, or insulators, with specified reference coatings. The insulator withstand voltage is the maximum value of voltage which may be applied to a test specimen on three consecutive trials without flashover at a given level of layer conductivity.

C. SCOPE OF TESTS

1. The procedure outlined in this memorandum applies to the testing of porcelain suspension insulators of nominal voltages greater than 1 KV, which are used outdoors and exposed to polluted atmospheres. At present, this procedure is limited to A.C. voltage tests, and is not intended to be used for insulators of organic material or to determine the efficiency of different surface treatments, such as silicone compounds. The general procedure is known as the wet-contaminant method and is generally in agreement with that described by F. J. Turner and B. Macchiaroli.[1]

The voltage source used in making these tests should have a short circuit current not less than 5 amperes RMS.

2. Cleaning of Insulators

The insulators shall be carefully cleaned so that all traces of grease are removed. Detergent may be used, after which the insulator surface shall be thoroughly rinsed with clear water to remove remaining traces of any ionizing material. The surface of the insulator is deemed sufficiently clean and free from any grease if large continuous wet areas are observed. After washing, insulators shall be dried by blowing compressed air on the surfaces.

[1]IEEE Paper No. 69-TP-692 "A Study of Some Variabiles Affecting Contamination Testing Using the Wet Contamination Method" B. Macchiaroli and F. J. Turner.

IEEE Paper No. 69-TP-14 "A New Contamination Test Method" B. Macchiaroli and F. J. Turner.

voltage shall be about 2 KV per meter of the arcing distance of the insulator. The conductance can then be calculated and finally the surface conductivity can be determined by multiplying the conductance by the form factor for the surface being investigated. (See Appendix I)

4. The average salt deposit density on the insulator shall be measured by washing the entire surface of the insulator and collecting the wash water. The water obtained from washing of the insulator shall be filtered, and the residue dried and weighed. Knowing the original proportions of the mixture and the surface area of the insulator, the average salt density can be obtained and expressed as mg of salt per cm^2 of insulator surface.

G. TEST PROCEDURE

Five minutes after the coating process and while the insulators are still wet, voltage shall be applied and increased at a constant rate of about 7.5 KV per second. Voltage shall be increased to flashover and recorded.

The insulator shall next be washed, recoated and tested, except that voltage applied to the insulator shall be 10% below the flashover value obtained on the first test. The test voltage shall be maintained until flashover or for five minutes, if no flashover occurs.

The complete test (starting with the cleaning) shall be repeated several more times until three consecutive withstands and no flashovers are obtained at same voltage level. The voltage level obtained for the particular contamination level shall be called the withstand voltage.

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APPENDIX I

Determination of the Layer Conductivity

Definitions:

1. Layer conductance of the deposit of contaminate on the insulator is the conductance of the pollution layer as measured in accordance with Par. 4.C.

2. Layer conductivity is the value of the layer conductance multiplied by the form factor.

3. Form factor shall be determined from the insulator dimensions. For graphical estimation of the form factor, the reciprocal value of the insulator circumference (1/b) is drawn against the leakage path"s". The form factor is given by the area under this curve and calculated according to the formula:

$$f = \int_0^s \frac{ds}{b(s)}$$

The layer conductivity "K" shall be referred to a reference temperature of 20°C using the following formula:

$$K_{20} = K_t \times \frac{1.6}{1+0.03t}$$

Where "T" is the temperature of the insulator surface in °C.

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B. Macchiaroli
Inst.of Electrical Engineering
University of Naples
Naples, Italy.

F. J. Turner
Senior Member IEEE
General Electric Company
Pittsfield, Mass.

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A NEW CONTAMINATION TEST METHOD

B. Macchiaroli*
Institute of Electrical Engineering
University of Naples
Naples, Italy

F. J. Turner
High Voltage Laboratory
General Electric Company
Pittsfield, Massachusetts

ABSTRACT

A contamination test method is proposed that can be applied in any existing laboratory without adding expensive new facilities or equipment. The method can be applied to practically any piece of apparatus such as suspension insulators, bushings, lightning arresters, and station equipment.

In conjunction with the new test method a new contamination slurry is proposed. A large amount of data is presented concerning the physical and electrical properties of the proposed slurry and the reproducibility of the results.

INTRODUCTION

The artificial contamination methods now being employed by various laboratories around the world are all useful for development work, but they are generally designed for the investigation of certain natural conditions existing in specific areas. These methods generally require special and expensive test facilities and moreover it is often difficult to reproduce results among laboratories due to the many variables present, both in the method of making the test and in the composition of the contaminating slurries.

There is a need for a standard contamination test that can be performed readily in any laboratory with its existing facilities. The following prerequisites are suggested for such a test.

1. No special rooms or facilities should be required.
2. It must be capable of being applied to all apparatus.
3. The materials used in the contaminating slurry must be pure in the sense that they have the same physical and chemical characteristics at all locations.
4. The equipment used must be simple so that it can be duplicated readily.
5. The test method must have a minimum of arbitrary variables so that it is not dependent on the skill and experience of the operator.
6. The variability of the test results must be minimal.
7. The time required for the performance of the test and evaluation of the results should not be excessive.

With the preceeding factors in mind the authors have developed and thoroughly investigated the "wet contaminant" test method described in this paper.

THE WET CONTAMINANT METHOD

In selecting a contamination test method there are two general philosophies that can be followed:

1. The contamination can be put on selectively in a manner simulating natural conditions.
2. An attempt can be made to produce a uniform coat over the entire insulator surface.

Proponents of #1 argue that in the natural state contaminant is not as readily deposited on the protected surfaces of insulators of the fog type, and therefore any proposed test method should evaluate this protective quality.

Proponents of #2 argue that protected surfaces are only free of pollution during the early periods of exposure, and that insulators out in service for any reasonable period of time have as much or greater deposits of contaminant on the protected surfaces as they do on those exposed.

Undoubtedly both of the above arguments have merit and represent observations of people from different localities concerning conditions that exist in those particular areas.

It is the opinion of the authors that a standard test should take into consideration the most severe conditions, and therefore it was decided to use a variation of the uniform coating technique.

Two general methods have been used to obtain a uniform or semi-uniform coat. One method is to apply a fine spray to the insulating surface while the spray gun and insulators are moved relative to each other until in the operator's judgment a uniform coat has been produced. This method depends to a great extent upon the operator's judgment as to when he has a uniform coat, and also it is difficult to control the coating thickness. The second method consists simply of dipping the insulators in the contaminating liquid. By this method the coating can be reproduced quite readily, providing that the insulator surface has been prepared in a specified way before dipping. The main difficulty with this method is that it is almost impossible

*B. Macchiaroli was in the High Voltage Laboratory of General Electric Co., Pittsfield, Mass. on a NATO-CNR scholarship.

to dip large bushings, lightning arresters, and other large apparatus. It was therefore decided to use a variation of the dipping method that achieves identical results. That is, the insulators are flow-coated starting at the top and working to the bottom with a stream of liquid that coats the complete surface to the point of run-off. Previous to the flow-coating operation the insulators are prepared by washing in a neutral detergent, rinsing with tap water, and drying with compressed air. It has been found possible to design apparatus to flow-coat large structures and the resultant coating has been found to be quite reproducible. The quantity of the coating, however, in milligrams per square centimeter is somewhat less on the underside than on the top. This is also true of the dipping method and is probably due to the tendency to drip from the vertical surfaces. Furthermore, the flow-coating process can be carried on in any laboratory test area, and the residue flushed down the drain after test.

In the proposed "wet contaminant" test method the testing starts while the insulators are still wet, three to five minutes after the end of the flow-coating process. Although the objective of this test method is to determine the highest withstand voltage, initially a flashover is obtained to establish the voltage range. Therefore the voltage is brought up at a rate of about 7.5 kV/s to the flashover level, and the voltage recorded. A second test is then made repeating the whole washing, contaminating, and testing procedure except that this time an attempt is made to hold a withstand voltage ten percent below the flashover value. The complete test is repeated several more times until three withstands and no flashovers are received at some voltage level. This is then called the withstand voltage for the particular contamination level applied and is usually determined within five percent.

The above describes the method when used for development work to obtain design data. When used for a standard acceptance test method, one or more tests at the required withstand voltage can be specified.

There are two factors involved in this method that contribute to reproducible results. First, it has been found that with a little care the flow-coating nozzles can be shaped so that all of the insulator surfaces are covered to the point of run-off. The coating efficiency can be readily inspected by examination when wet, before applying the voltage, and also after the insulators have dried. Second, the flashover strength is dependent upon the amount of water held on the surface as well as the amount of solid material deposited. In the case of the "wet contaminant" method all tests are made with the surface completely wet.

The apparatus used to accomplish the flow-coating can be readily constructed from copper tubing. In Figure #1 is shown the apparatus used to coat suspension insulators. In this figure the contaminating liquid is pumped under pressure to the continuous copper ring which surrounds the insulators. On the inside surface of the ring 16 short sections of copper tubing about 6 mm in diameter (1/4") protrude. Half of these have a slight curve upward and sidewards so that the liquid is directed up along the grooves on the underside of the insulators. To illustrate the versatility of this method, Figure #2 shows one of the largest lightning arresters in the process of being flow-coated.

The degree of contamination on the insulator surface can be measured in several ways. First, the amount of salt and binder in the flow-coating liquid can be specified. Second, since the contamination coating is not altered by the test, all or part of an insulator coating may be washed off in distilled water, the conductivity measured, and the amount of salt in solution determined by comparison with standard curves. The equivalent salt deposit density can then be computed. Third, before applying high voltage to the test specimen a low voltage can be applied, and the leakage current measured. The conductance can then be computed, and finally the surface conductivity can be calculated by multiplying the conductance by the form factor for the surface being investigated.

The form factor is not generally available and must be calculated from measurements made on a drawing of the insulator cross section using the formula

$$f = \int_0^{\ell} \frac{d\ell}{\pi D(\ell)}$$

where ℓ denotes the total length of the leakage path and $D(\ell)$ the diameter of each element of the leakage path.

In the present investigation all of the above methods of measuring the surface pollution were used, but the authors believe that the best correlation with withstand strength can be obtained with surface conductivity.

In regard to the power source used for making contamination tests, other investigators have found, and it has been confirmed here, that there must be sufficient short circuit current available to prevent a voltage dip when flashover is imminent. It was found that with a small amount of pollution a source of five amperes was sufficient, but that as the contamination increased ten amperes or more were necessary.

THE CONTAMINATING MIXTURE

One of the objections to the clean fog method and other similar methods of test has been the variability of the constituents used in the contaminating slurry. Many types of

binders have been used such as Kaolin, Kieselgur and Aerosil. It was decided to try a pure form of SiO_2 which is readily available under the trade name Cab-O-Sil. This is a pyrogenic silica having an extremely small particle size. It is produced by the hydrolysis of silicon tetrachloride at 1100°C, and it is more than 99% pure. The basic chemical reaction is:

$$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$$

The large number of individual particles formed a group together in a chain like formation, and when dispersed in a liquid system, these "chains" join each other and form a "chicken wire" type of structure which entraps the liquid. This reduces the ability of the liquid to flow, and results in an increase of the viscosity.

After a great deal of experimenting with Cab-O-Sil it was found that the addition of a small amount of additive increased the viscosity and resulted in a gelatin like deposit that has the ability to hold liquid for a long period of time. The manufacturers of Cab-O-Sil suggested several additives, but none were more effective for the present application or as easily obtainable as the wetting agent called Photo-Flo manufactured by the Eastman Kodak Company.

In order to determine the final contaminating mixture to be used throughout the investigation a large number of tests were performed. The aim of this part of the investigation was to determine the mixture that would remain in a stable wet condition for a long period of time.

These basic tests were performed on a string of five standard 5-3/4" by 10" (146 mm by 254 mm) Locke insulators having an outline as shown in Figure #3. The coatings were evaluated for the ability to hold moisture by applying a low voltage and measuring the leakage current versus time. Leakage current measurements were started in all cases three minutes after the flow-coating process was completed. The drying time can vary with the power dissipated; therefore in order to compare all coatings under the same conditions, the applied voltage was adjusted for each degree of contamination to maintain the power consumption below two watts.

For each mixture investigated five tests were made. After each test, the density of the salt deposit was determined on the top insulator of the string, the bottom insulator of the string, one additional insulator flow-coated but not tested, and finally one insulator that was coated by dipping in the same slurry. Measurements of the density of the salt deposit were made not only for the whole insulating surface, but also for the top and bottom surfaces separately. The top surface was defined for this purpose as that area wetted by a vertical rain when the insulator is hanging vertical.

The results of these basic tests to evaluate the various mixtures are presented in Figures #4 through #8 and Table I.

The surface conductivity of the insulators was used as a measure of the ability of the contaminant to hold water over a period of time. The average value of this quantity is plotted versus time after flow-coating in Figures #4 and #5 for a binder containing 2.5 grams per liter of Cab-O-Sil and 25 grams per liter of Cab-O-Sil respectively with various concentrations of salt from 2 to 100 grams per liter in each case. In addition, tests were made with 50 grams per liter of Cab-O-Sil, but it was found that the viscosity of the slurry was not stable for such a large concentration.

In Figure #6 the results obtained with 20 grams per liter of Cab-O-Sil and an additive of 1 gram per liter of Photo-Flo 600 are shown. This amount of Photo-Flo additive was found to be sufficient by making several preliminary tests.

At the left of each of the curves in Figures #4 through #6 are shown two numbers separated by a diagonal. These represent the initial variability of the results obtained for the five tests and the variability after 10 minutes. Thus, for 50 grams per liter in Figure #4, there was an initial dispersion in the conductivity measurements of ± 10% and this grew to ± 35% after 10 minutes.

In Table I the percent conductivity changes with respect to the initial, for times after flow-coating of 10 minutes and 15 minutes, have been tabulated for the various mixtures. From these tests the following conclusions may be drawn:

1. With salt alone for a contaminant the initial surface conductivity is low, has a wide variation, and the surface dries rapidly.

2. For a given amount of salt the initial surface conductivity increases with the amount of Cab-O-Sil. Although 25 grams per liter of Cab-O-Sil results in a fairly constant conductivity for the first 10 minutes when above 25 grams per liter of salt are used, the change is very large for low salt concentrations. Using 50 grams per liter of Cab-O-Sil gave better results, but it was found difficult to maintain a constant viscosity mixture, and this resulted in a large dispersion in the surface conductivity.

3. By far the most stable results were obtained when 1 gram per liter of Photo-Flo 600 was added to a slurry containing 20 grams per liter of Cab-O-Sil. Figure #6 summarizes the data for this mixture, and it can be seen that the maximum variation in the initial conductivity was only 2%, and the decrease over 30 minutes was very small. Table I shows that the maximum change in conductivity over a 10 minute period was only 4% and after 15 minutes 6%. Thus, with this binder, for a given salt concentration there will be negligible variation in the initial conductivity of the insulators, the degree of wetness of each insulator will be the same, and it is not necessary to closely control the time at which the voltage is applied after the flow-coating has been completed.

4. The amount of salt on the upper surface, lower surface, and the average for the complete insulator are shown in Figure #7. From this figure it can be seen that the density of the salt deposit is linear with the salt in the slurry. It also increases with the amount of Cab-O-Sil and is the highest when the Photo-Flo additive is used. For all cases, the salt density on the upper surface is greater than that for the lower surface. This is also true for the dipping method of contamination and does not affect the overall value of the test method.

5. The dispersion of the density of the salt deposit on the insulator surfaces from test to test was found to be generally less than 15 percent although it occasionally reached as high as 20 percent.

6. No difference in the amount of salt deposit was found between the dipping and flow-coating methods.

7. The use of the Photo-Flo additive results in an increase in both the salt deposit density and the surface conductivity; therefore, less salt is required in the slurry to achieve a given degree of contamination.

8. In Figure #8 a plot is shown on log-log paper of surface conductivity versus grams per liter of salt for three levels of Cab-O-Sil binder. When plotted on this type of paper, a linear relation was found for all three cases.

EFFECT OF TEMPERATURE AND HUMIDITY

All of the tests up to this time were performed with both the mixture and ambient temperature in the range of 22°C to 25°C. Since conductivity often is a function of temperature, it was decided to determine the effects of relatively large differentials in temperature between ambient and mixture. Accordingly, additional conductivity measurements were made for several mixtures on insulator strings with the ambient temperature in the range of 22°C to 25°C and a mixture temperature of 12°C to 13°C. Also, the ambient temperature was lowered to 7°C to 8°C and tests made with mixture temperatures around 22°C. For all of these tests the results have been within the spread that could be expected from test to test with different slurries; therefore, it can be concluded that the temperature of the ambient and mixture within a reasonable range has no appreciable effect on the surface conductivity.

Similarly, the ambient humidity has been varied from 15 percent to 70 percent with no noticeable effect on the data.

TESTS ON INSULATOR STRINGS

As a result of the information gathered in the investigation of the contamination coating, it was decided to make all further withstand and flashover tests with a contamination slurry containing 20 grams per liter of Cab-O-Sil, 1 gram per liter of Photo-Flo 600, and various levels of salt to achieve the contamination level desired.

Withstand and flashover tests were performed on suspension insulator strings composed of two types of insulators:

(1) 9 standard Locke units, Cat. 1840K
(2) 8 fog-type Locke units, Cat. 18134.

The main characteristics of these insulators are tabulated in Table II and shown in Figure #3.

The tests were carried out for salt concentrations from 2 grams per liter to 20 grams per liter in the manner already described, and for each test measurements were made of both the salt deposit density and initial surface conductivity. These quantities are shown in Figures #9 and #10, and the withstand voltages are shown in Figures #11, #12 and #13. In Figures #11 through #13 it is seen that the relative withstand values of the two insulator strings are the same whether plotted against grams per liter of salt in the slurry, density of deposit on the surface, or conductivity of the surface. In each case a curve is obtained which is apparently leveling off as large concentrations of salt are reached. In each case the fog-type insulator is somewhat superior to the standard insulator, a situation that was somewhat expected based on the longer creepage path. The difference in strength is most apparent when plotted against the grams of salt per liter of solution. This is caused by a higher average salt deposit per square centimeter on the standard type unit which results in a higher conductivity. These differences in average salt deposit density and surface conductivity are due to the larger lower area of the fog-type units where the salt density is less, as already mentioned. When plotted against salt deposit density or surface conductivity, however, the effect of the larger area of the underneath portions of the fog-type units is eliminated, and the insulators are compared in a more realistic fashion on the merits of the contour design. It can also be argued that surface conductivity is a more basic quality, and therefore a more suitable basis for comparison. On the other hand, it is the most difficult of the measurements to make or predict, and therefore may be less desirable from a practical standpoint.

As a matter of interest, oscillograms of the leakage current and line voltage are shown in Figures #14 through #16. Figure #14 shows on a relatively fast sweep the distortion that occurs in the current wave due to the streamers that occur during a withstand run very near the flashover

level. Note that the voltage source is so stiff that it is relatively unaffected. Figure #15 gives a record of the overall activity that occurs during a withstand run, and Figure #16 shows a flashover. In Figure #17 is shown the scintillation that occurs on the insulators during a withstand run that is very close to the flashover voltage.

TEST REPRODUCIBILITY - THEORETICAL APPROACH

In order to come to some conclusions as to the reproducibility of the results obtained with the proposed test method, an attempt has been made to analyze the variability in the withstand voltage that can result from the parameters involved. These are:

1. salt deposit density on the insulator surfaces,
2. wetting degree at the moment of test,
3. layer thickness,
4. layer temperature,
5. rate of voltage increase.

Another important variable is the short circuit current of the power supply concerning which it has already been stated that it must be large enough to hold the voltage constant during periods of heavy scintillation. When this condition is complied with, there is no appreciable influence on the results.

Considering the first four parameters, it is noted that they can be lumped together under surface conductivity. Therefore, we can consider that the withstand voltage V_w is a function of:

$$V_w = f\left(c, \frac{dV}{dt}\right) \qquad (1)$$

where c is the surface conductivity and $\frac{dV}{dt}$ the rate at which the voltage is increased to the withstand level. Accordingly, changes or variations in the withstand voltage can be expressed as:

$$dV_w = \frac{\partial V_w}{\partial c}\,dc + \frac{\partial V_w}{\partial\left(\frac{dV}{dt}\right)}\,\frac{d\left(\frac{dV}{dt}\right)}{dt} + \Delta \qquad (2)$$

Here the quantity Δ has been added to account for the dispersion in results that could be obtained due to the statistical variation of unknown factors in the breakdown process even if all other quantities were held constant.

The term $\frac{\partial V_w}{\partial c}$ is the slope of the tangent to the curve of withstand voltage versus surface conductivity. This value changes with the surface conductivity. Representative values are as follows:

$\frac{\partial V_w}{\partial c}$		μS 15	30	60
	Std.	2.2	0.83	0.31
	Fog	1.9	0.86	0.31

The term, dc, can be considered as the variability that can exist in the surface conductivity from test to test for the same slurry. In Figure #6 it is seen that when working with the same slurry a variability of 2% has been found. However, when different slurries are mixed up it is estimated that an error of 2% is possible in each measurement. Since there are four components in the slurry, the estimated error in preparing a slurry could reach 8%. Therefore, for tests made at different times with different mixtures the total conductivity variability from this cause could reach 10%.

In order to obtain an approximation for the term $\frac{\partial V_w}{\partial\left(\frac{dV}{dt}\right)}$ a large number of tests are necessary with the same slurry so that the change due to surface conductivity is minimal. This is quite difficult due to the time involved and the quantity of the same mixture required; therefore, it was decided to work with the flashover voltage, V_f, instead and use the results as a reasonable approximation for those that would have been obtained for V_w.

Tests were carried out on standard insulators for two different salt concentrations, and the results are shown in Figure #18. The two curves obtained are in fairly good agreement and the following observations can be made:

a. The $\frac{\partial V_f}{\partial\left(\frac{dV}{dt}\right)}$ as determined by the slopes of the curves in Figure #18 decreases when going from 3 kV per second to 12 kV per second for both curves with some average values as follows:

Rate of Rise	$\frac{\partial V_f}{\partial\left(\frac{dV}{dt}\right)}$
5 kV/s	- 1.2
7.5 kV/s	- 0.4
10 kV/s	- 0.07

b. Because of the variability of the data in Figure #18, a band should be considered rather than a single line through it. This can be accounted for to some degree by variations in surface conductivity, but is is probably more likely due to the unknown factors combined under Δ in equation (2). In any event, the dispersion of results is greatest for slow rates or rise, being about ± 5% at 3 to 4 kV per second and ± 3% at 7 to 8 kV per second.

c. When working in this voltage range it is

difficult to control the voltage for rates of rise greater than 10 kV per second.

Based on the above observations, a voltage rate-of-rise of 7.5 kV per second was selected as standard for this voltage range. If we assume that we can maintain a speed of 7.5 kV per second within ± 15%, then the term

$$\frac{\partial V_f}{\partial\left(\frac{dV}{dt}\right)}\left(\frac{dV}{dt}\right) \text{ becomes } (-0.4)(\pm 15\%) = \pm 6\%$$

Adding up all of the terms for equation (2), for a conductivity of 53 microsiemens which corresponds to a salt content of 10 grams per liter for standard insulators, we have the following:

$$dV_w = (0.35)(10) + (.4)(15) + 3 \approx 12\%$$

In a similar manner the expected variability for V_w can be calculated for other conductivity values to yield the following table:

Salt in Mixture g/ℓ	dV_w Std. Ins.	Fog Ins.
5	19%	23%
10	12%	14%
20	9%	9%

This variability is what could be expected when different mixtures used for several withstand tests and the withstand values are plotted versus salt in the slurry or on the surface.

On the other hand during the present investigation, when only one slurry was used for one complete test series, only a 2% variation in the initial conductivity was found. In this case the 8% error possible due to using different mixes has been eliminated and the expected variability in the withstand values becomes:

Surface Conductivity (μS)	dV_w Std. Ins.	Fog Ins.
15	13%	13%
30	11%	11%
60	10%	10%

TEST REPRODUCIBILITY - EXPERIMENTAL

In order to verify that the withstand voltages for tests conducted at different times would fall within the theoretically calculated range, the withstand tests were repeated after a time interval of two months. In this second series of tests, both a different test area and a different operator were used.

The results of this second series of tests are plotted in Figures #11 through #13 and a comparison with the original values is tabulated in Table III. From Table III it is seen that the results are in surprisingly good agreement with the initial tests, and the percent change is well within the calculated limits for each salt concentration.

The reproducibility of results found here is much better than usual for contamination testing, and at the present time it is not known whether it is due to the test method, the slurry composition, or a combination of both. It would be interesting to investigate the reproducibility of results with the same test method but different binders in the slurry.

CONCLUSIONS

1. A new contamination test method has been proposed that can readily be applied to all types of insulating structures, and does not require highly specialized equipment or test facilities.

2. The proposed test method is not intended to reproduce any particular natural conditions, but with experience correlation could come naturally as data are accumulated in service for insulating structures that have been tested by the new method.

3. A new contaminating slurry has been developed which is composed of well defined materials and has the ability to hold its original wet condition over an appreciable time. The salt deposit density and the surface conductivity of insulators contaminated with this slurry are independent of both ambient temperature and humidity and also that of the slurry temperature.

4. It is the authors' opinion that the surface conductivity of the insulators should be used as a measure of the degree of contamination.

5. Although further work is required, it appears that the reproducibility of results with the new method is good enough so that it can be considered for a standard contamination test. It would be desirable for some other laboratory to perform a series of withstand tests in order to check the results obtained and determine if any problems exist in this respect.

Table I. Percentage Conductivity Change with Respect to Initial Value

Binder		After 10 Minutes				After 15 Minutes			
Cab-O-Sil g/l	Photo-Flo g/l	Salt g/l 2	25	50	100	Salt g/l 2	25	50	100
2.5	0	88	75	55	38	98	100	100	70
25	0	53	9	9	11	88	14	20	24
50	0	9							
20	1	4	3	1	2	6	4	3	5

Table II. Main Characteristics of Tested Strings

Insulator Type	Number of Units	Overall Length mm	Leakage Path mm
Standard Disk	9	1314	2630
Fog Disk	8	1320	3450

Table III. Comparison of Two Test Cycles for Various Salt Concentrations

		Insulators Standard				Fog		
Salt in Mixture	(g/l)	2	5	10	20	5	10	20
Withstand Voltage First Test	(kV)	115	77	61	53.5	97	76	63
Withstand Voltage Repeated Tests	(kV)	125	80	58	51	94	71	60.5
Percentage Change of repeated test with respect to the first	(%)	+9	+4	-5	-5	-3	-7	-4

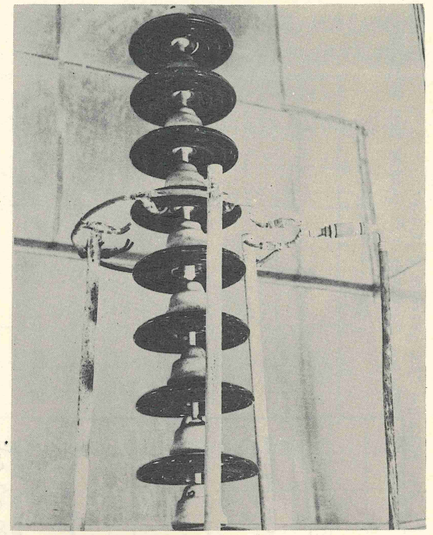


Fig. 1. Apparatus for Flow-coating Suspension Insulators.

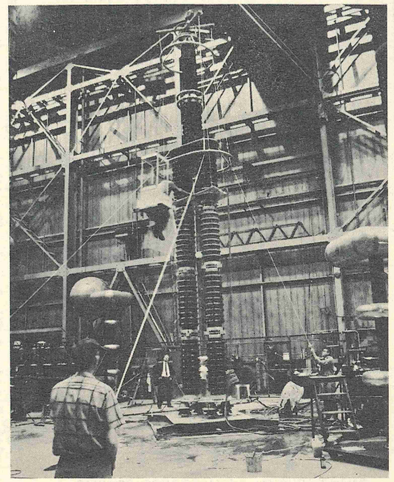


Fig. 2. Flow-coating Method Being Applied to a Lightning Arrester.

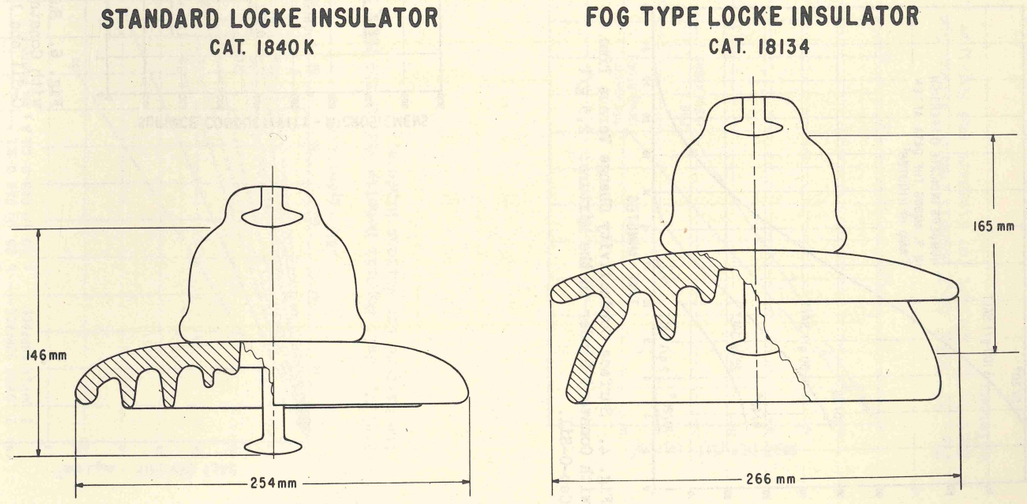


Fig. 3. Test Insulators.

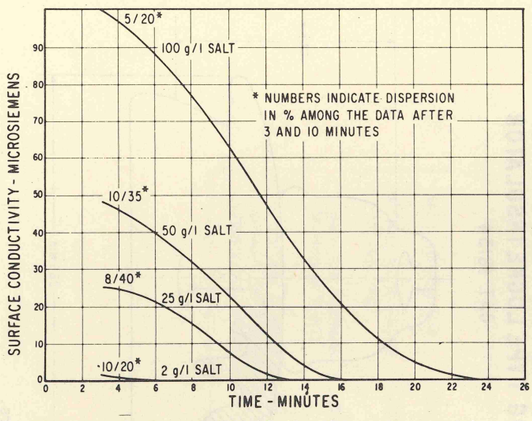


Fig. 4. Surface Conductivity Change Versus Time with Constant Binder in the Mixture: 2.5 g/l Cab-O-Sil.

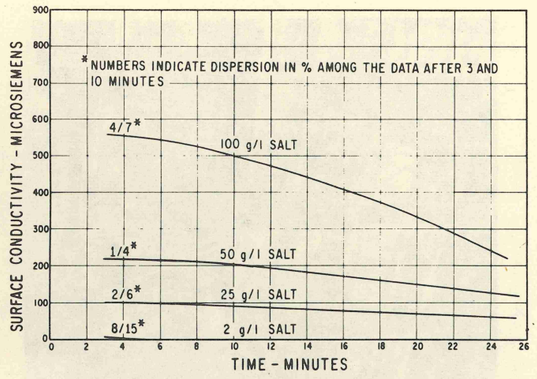


Fig. 5. Surface Conductivity Change Versus Time with Constant Binder in the Mixture: 25 g/l Cab-O-Sil.

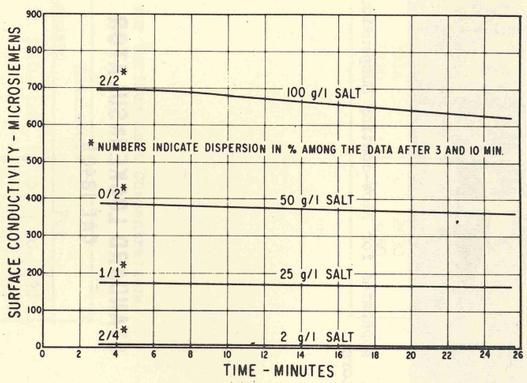


Fig. 6. Surface Conductivity Change Versus Time with Constant Binder in the Mixture: 20 g/l Cab-O-Sil and 1 g/l Photo-Flo.

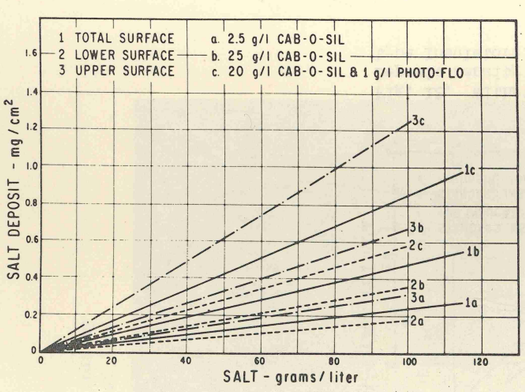


Fig. 7. Salt Deposit Density Versus the Salt in the Mixture for Various Binders.

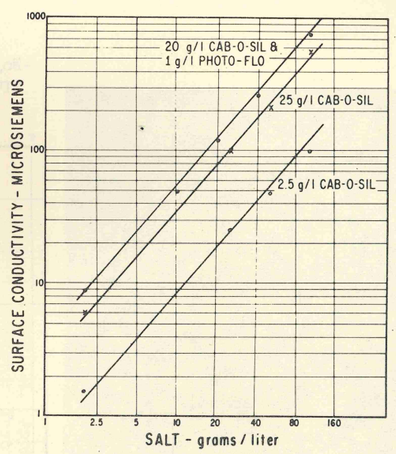


Fig. 8. Surface Conductivity Versus the Salt in the Mixture for Various Binders.

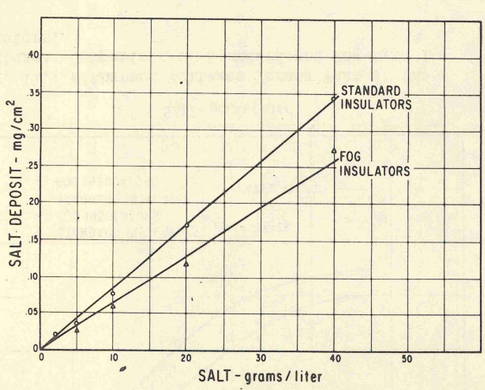


Fig. 9. Total Salt Deposit Density Versus the Salt in the Mixture for Standard and Fog-type Insulators.

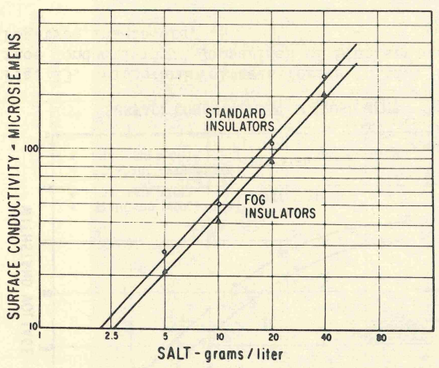


Fig. 10. Initial Surface Conductivity Versus the Salt in the Mixture for Standard and Fog-type Insulators.

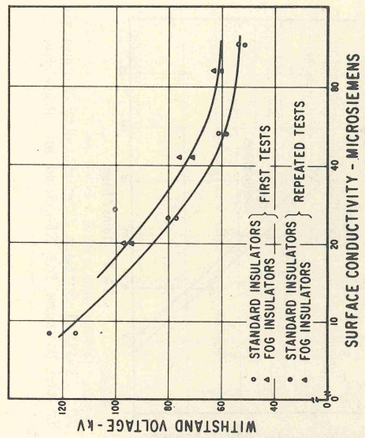


Fig. 13. Withstand Voltages Versus Initial Surface Conductivity: Comparison of Standard and Fog-type Insulators.

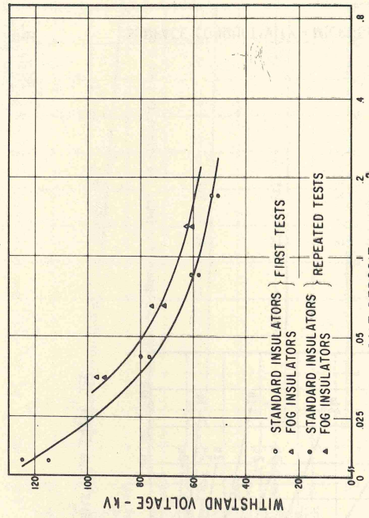


Fig. 12. Withstand Voltages Versus Average Salt Deposit Density: Comparison of Standard and Fog-type Insulators.

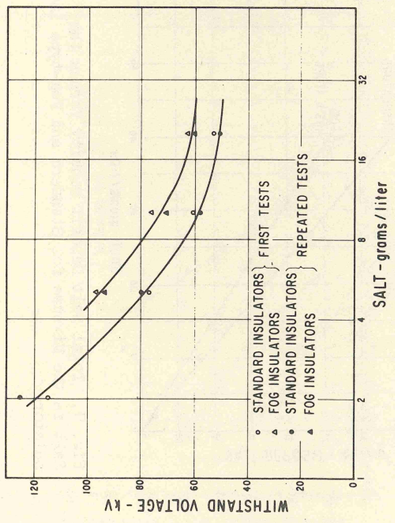


Fig. 11. Withstand Voltages Versus Salt in the Mixture: Comparison of Standard and Fog-type Insulators.

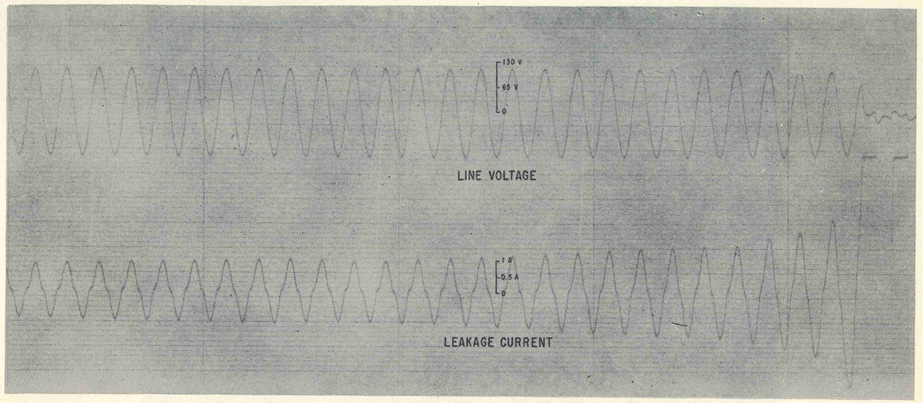


Fig. 14. Applied Voltage and Leakage Current Record: Test with Flashover Showing Wave Distortion.

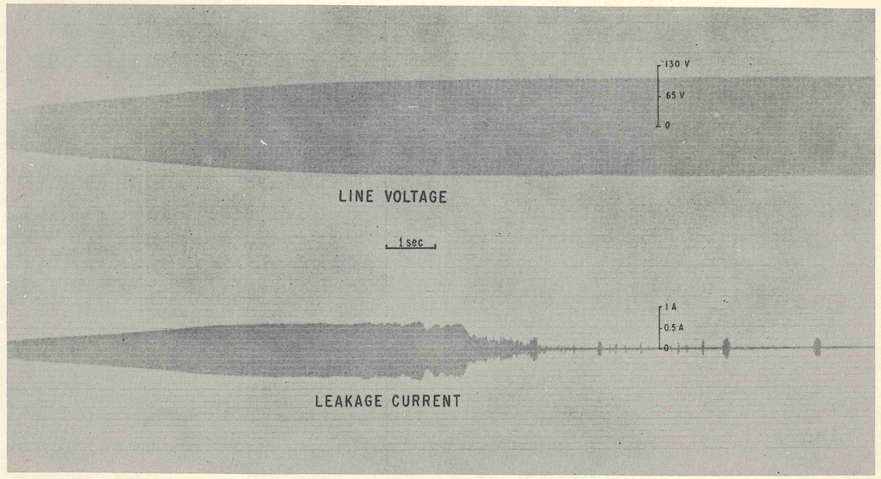


Fig. 15. Applied Voltage and Leakage Current Record: Test with Withstand.

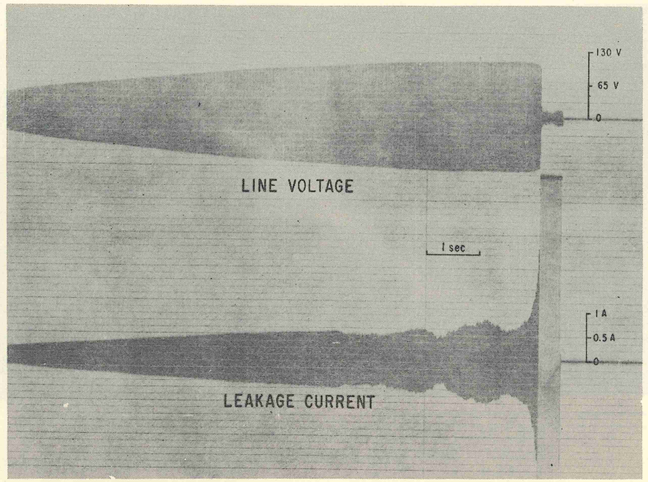


Fig. 16. Applied Voltage and Leakage Current Record: Test with Flashover.

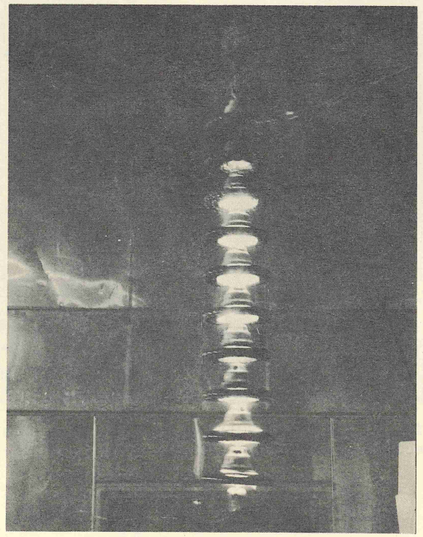


Fig. 17. Scintillation on Standard Insulator String During a Withstand Test.

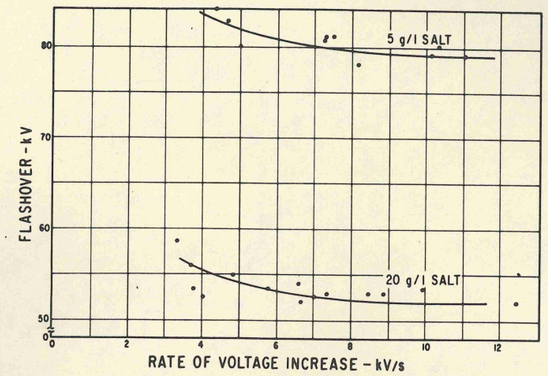
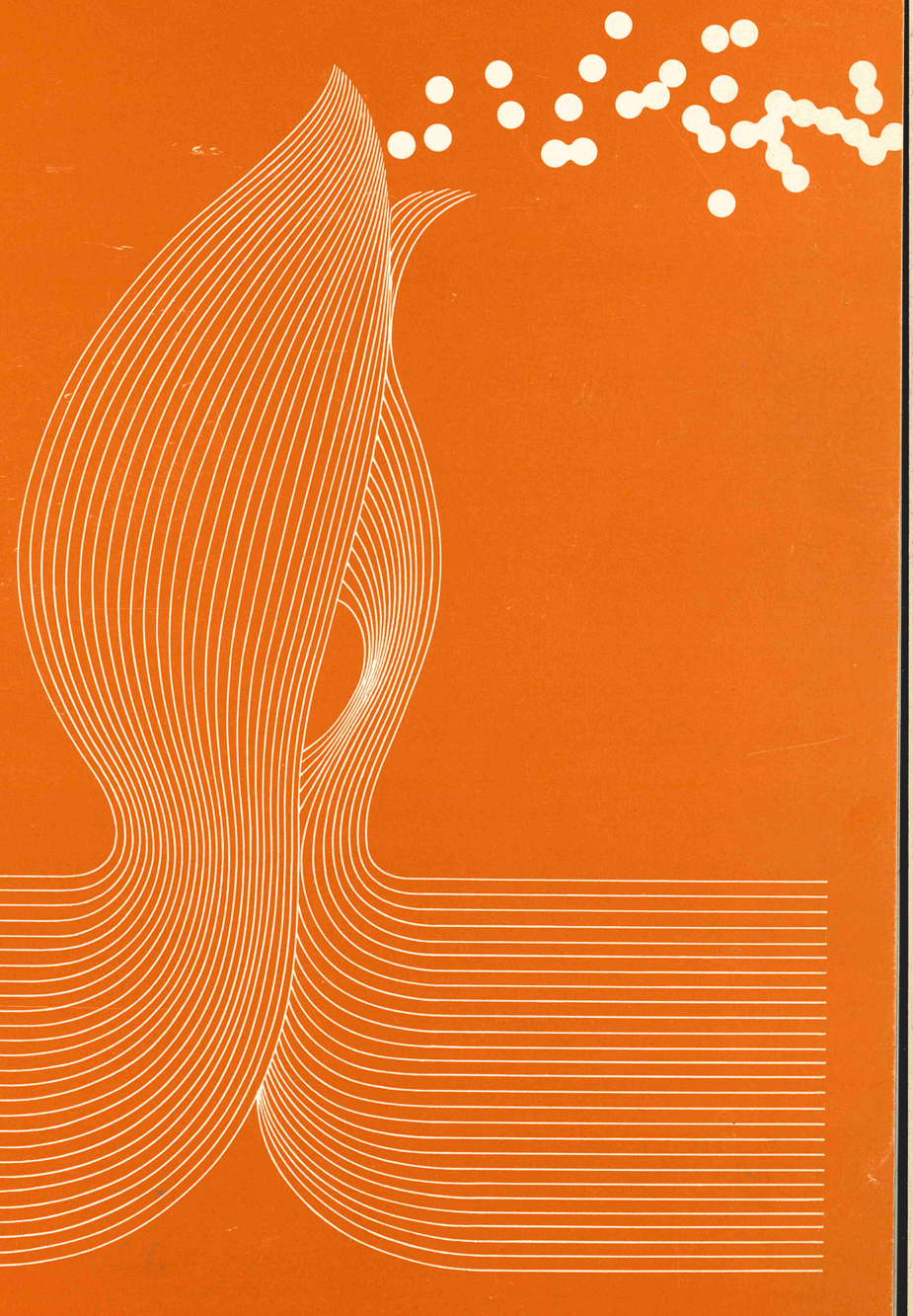


Fig. 18. Flashover Voltage Versus Rate of Voltage Increase for Slurries with Two Different Salt Concentrations.

CAB-O-SIL®

How to use it
Where to use it



GENERAL ELECTRIC

REQUEST FOR QUOTATION

THIS IS NOT AN ORDER

HAMPDEN COLOR & CHEMICAL CO.
126 MEMORIAL DRIVE
SPRINGFIELD, MASS. 011

Gentlemen:

Please quote us immediately in TRIPLICATE, on the following to be delivered as requested, indicating if you can fulfill delivery requirements stated below or otherwise your best shipping promise. If special tooling is required for which we will be charged, quote same separately and state time required for its completion.

Quotations must state shipping point, net terms of payment, and discount for cash, and must be subject to the conditions on the reverse side of this form.

1	2	3	4	5	6

SEP 18 1969

7	8	9	10	11	12

Changes or suggestions offering cost economy are solicited.

TI-425 (7-56)

Please Address Reply *to*

GENERAL ELECTRIC COMPANY
INSULATOR DEPARTMENT
2525 Insulator Drive
Baltimore, Md. 21230
Attn: RJ MYTKE, Buyer

REFER TO:
REQUEST NO. 69-147

SEE REVERSE SIDE FOR STANDARD CONDITIONS OF PURCHASE.
INQUIRY DATE 9/17/69

QUANTITY	DESCRIPTION
10 lbs.	CAB-O-SIL (pure form of SiO_2)
100 lbs.	

What Grade ?

Merrill S. Hobart

BID TO CLOSE	TERMS & F.O.B. POINT	DELIVERY TIME REQUIRED
9/19		

CABOT CORPORATION 125 HIGH STREET, BOSTON, MASSACHUSETTS 02110

CABLE ADDRESS "CABLAK" BOSTON
TEL. 617 423-6000

September 22, 1969

General Electric Company
Insulator Department
2525 Insulator Drive
Baltimore, Maryland 21230
ATTN: Mr. R. J. Mytke, Buyer

Dear Mr. Mytke:

This is in reference to your Request for Quotation Number 69-147. Cab-O-Sil M-5 is packaged in standard 10 lb. bags. The price for this material is as follows:

10 - 30 lbs.	$1.31 per lb.
40 - 190 lbs.	.99 per lb.

The terms are F.O.B. our warehouse in Philadelphia, Pennsylvania. The address of our Sales Office in Philadelphia is as follows:

Peltz/Rowley Company
937 North Front Street
Philadelphia, Pennsylvania 19123
(215) 627-3077

Enclosed for your convenience is our latest price schedule and other pertinent literature. If you have any further questions regarding this product, please do not hesitate to contact me personally.

Very truly yours,

CABOT CORPORATION

G. A. Campiola
Cab-O-Sil Customer
Sales and Services

GAC:rt

Enclosures

CABOT CORPORATION 125 HIGH STREET, BOSTON, MASSACHUSETTS 02110

CABLE ADDRESS "CABLAK" BOSTON
TEL. 617 423-6000

RECEIVED
SEP 24 1969
PURCHASING

September 22, 1969

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Cab-O-Sil Customer
Sales and Services

GAC:rt

Enclosures

WHERE TO ORDER CAB-O-SIL® SALES OFFICES

Main Office: CABOT CORPORATION, 125 High Street, Boston, Mass. 02110 (617) 423-6000

CALIFORNIA
Cabot Corporation
1820 Ogden Drive
Burlingame 94010
(San Fr.) (415) 697-1027

Cabot Corporation
3350 Wilshire Blvd.
Los Angeles 90005
(213) 382-7333

GEORGIA
Cabot Corporation
Lenox Towers
3400 Peachtree Road N.E.
Atlanta 30326
(404) 237-6415

ILLINOIS
Cabot Corporation
Oakbrook North Building
1200 Harger Road
Oak Brook 60521
(Chicago)
(312) 654-3230

MASSACHUSETTS
Cabot Corporation
125 High Street
Boston 02110
(617) 423-6000

NEW JERSEY
Cabot Corporation
P.O. Box 338
200 Raritan Center Parkway
Edison 08817
(201) 225-1000

NEW YORK
Refer to Edison, N.J.

OHIO
Cabot Corporation
3814 West Street
Cincinnati 45227
(513) 271-2160

Cabot Corporation
Westview Towers
21010 Center Ridge Road
Cleveland 44116
(216) 333-5350

TEXAS
Cabot Corporation
1712 Commerce St.
Dallas 75201
(214) 742-1391

CANADA

ONTARIO
Cabot Carbon of Canada, Ltd.
121 Richmond Street, West
Toronto 1
(416) 366-1608

QUEBEC
Cabot Carbon of Canada, Ltd.
5165 Sherbrooke Street, West
Montreal 28
(514) 489-9301

TYPICAL CHEMICAL AND PHYSICAL PROPERTIES OF CAB-O-SIL

CAB-O-SIL properties variable by grade

CAB-O-SIL Grades	EH-5	H-5	HS-5	L-5	M-5	MS-5	M-7	MS-7	M-7D	MS-75	S-17
*Surface area m^2/gm (BET)	390±40	325±25	325±25	50±10	200±25	200±25	200±25	200±25	200±25	255±15	400±20
Particle size micron	0.007	0.007	0.007	0.05	0.012	0.012	0.012	0.012	0.012	0.010	0.007
*Density lbs./cu. ft.	2.3 max.	2.3 max.	2.3 max.	7	2.3 max.	2.3 max.	4.0±0.2	4.0-5.0	6.0 min.	4.0-5.0	4.5±0.5
Ignition loss (1000°C. moisture-free basis)	2.5%	2%	2%	0.5%	1%	1%	1%	1%	1%	1.5%	2.5%
*pH (4% aqueous dispersion)	3.5-4.2	3.5-4.2	3.6-4.1	4.0	3.5-4.2	3.6-4.1	3.5-4.2	3.6-4.2	3.5-4.2	3.6-4.2	3.6-4.0
Net weight per bag (lbs.)	10	10	10	25	10	10	20	20	20	20	20

Identical properties — all grades

Bulking value, gal. per 100 lbs.	5.5
*325 Mesh residue – max.	0.02%
Silica content	99.8%
Specific gravity	2.2
Refractive index	1.46
Color	White
X-ray form	Amorphous

**Tested quality control specifications*

2313/966-R

U.S. PRICE LIST

CAB-O-SIL®

Fumed Silica

JULY, 1969
(Supersedes March, 1969 issue)
Prices subject to change without notice

GENERAL INFORMATION

How to figure cost — CAB-O-SIL can be shipped from any one of 26 warehouses in 20 states. The price for each grade of CAB-O-SIL is shown in the price schedule.

The base price of CAB-O-SIL is F.O.B. Tuscola, Ill. CAB-O-SIL can be shipped from Tuscola, Ill. to your plant in rail carload or truckload quantities.

Warehouse shipments of any grade of CAB-O-SIL will be on an F.O.B. warehouse basis.

How to order CAB-O-SIL — CAB-O-SIL is ordered by grade and quantity. Order a single bag to a carload. For economy, a minimum order of 4 bags is suggested.

The grades of CAB-O-SIL differ in physical properties (see Page 4). CAB-O-SIL M-5 is the grade most commonly used for thickening and free-flow applications.

Where to order CAB-O-SIL — CAB-O-SIL should be ordered from the nearest office listed on Page 4.

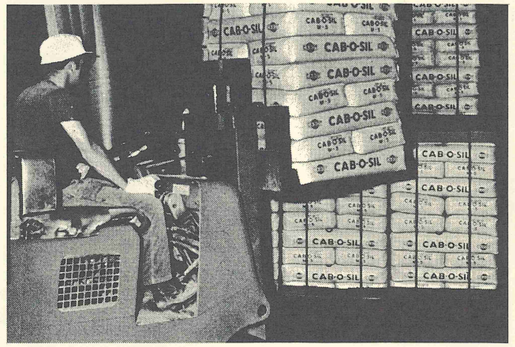
How CAB-O-SIL is packed — Because the particle size of CAB-O-SIL is as fine as cigarette smoke, it is bagged at the Tuscola plant under vacuum, in sealed, multiwall bags.

RAIL CARLOADS — A 12,000 or 20,000 pound minimum is the base for the shipping rate whether or not the minimum number of pounds is put in the car. How much CAB-O-SIL fits into the car depends upon the density of the grade being ordered, and whether Bulk Pack Units are used. A car measures 40′6″ long, 9′2″ wide, 10′ high, and has 3,700 cu. ft.

HOW MUCH FITS IN A RAIL CARLOAD

CAB-O-SIL Grade	Number of Bags	Gross Weight in Pounds	Weight of CAB-O-SIL Lbs.	Size Per Bag
M-5, MS-5	1,070 to 1,100	11,513 to 11,836	10,700 to 11,000†	36″ x 18″ x 9″
H-5, HS-5, EH-5	1,000 to 1,025	10,900 to 13,630	10,000 to 10,250	36½″ x 18½″ x 9½″
M-7, MS-7, M-7D, S-17 MS-75	940 to 960	19,700 to 20,200*	18,800 to 19,200	39″ x 19″ x 9″
L-5	1,070 to 1,100	27,552 to 28,325	26,750 to 27,500	35″ x 18″ x 9″

*Weight includes polyethylene overslips @ 0.18 lb. per bag.
†See Bulk Pack Units



MECHANIZE FREIGHT CAR UNLOADING and save costs on every bag of CAB-O-SIL you buy. One man with a fork lift can unload an entire car of BPUs in about two hours, an 87% savings in labor.

BULK PACK UNITS cut freight costs 15 to 17% on carload shipments

Standard freight cars from Tuscola, Ill. can carry 15,300 pounds of CAB-O-SIL in BPUs in the same car that used to take only 10,700 pounds in bags. This improved loading results in a direct reduction in freight costs. Cars can be loaded with 75/200-lb. Bulk Pack Units with 3/100-lb. units in the doorway.

Polyethylene overslips for moisture protection — Polyethylene overslips are available to protect contents from ambient moisture for all grades of CAB-O-SIL at an additional cost of 25¢ per bag. (Unless polyethylene overslips are specified, CAB-O-SIL is supplied in standard sealed, multiwall bags.)

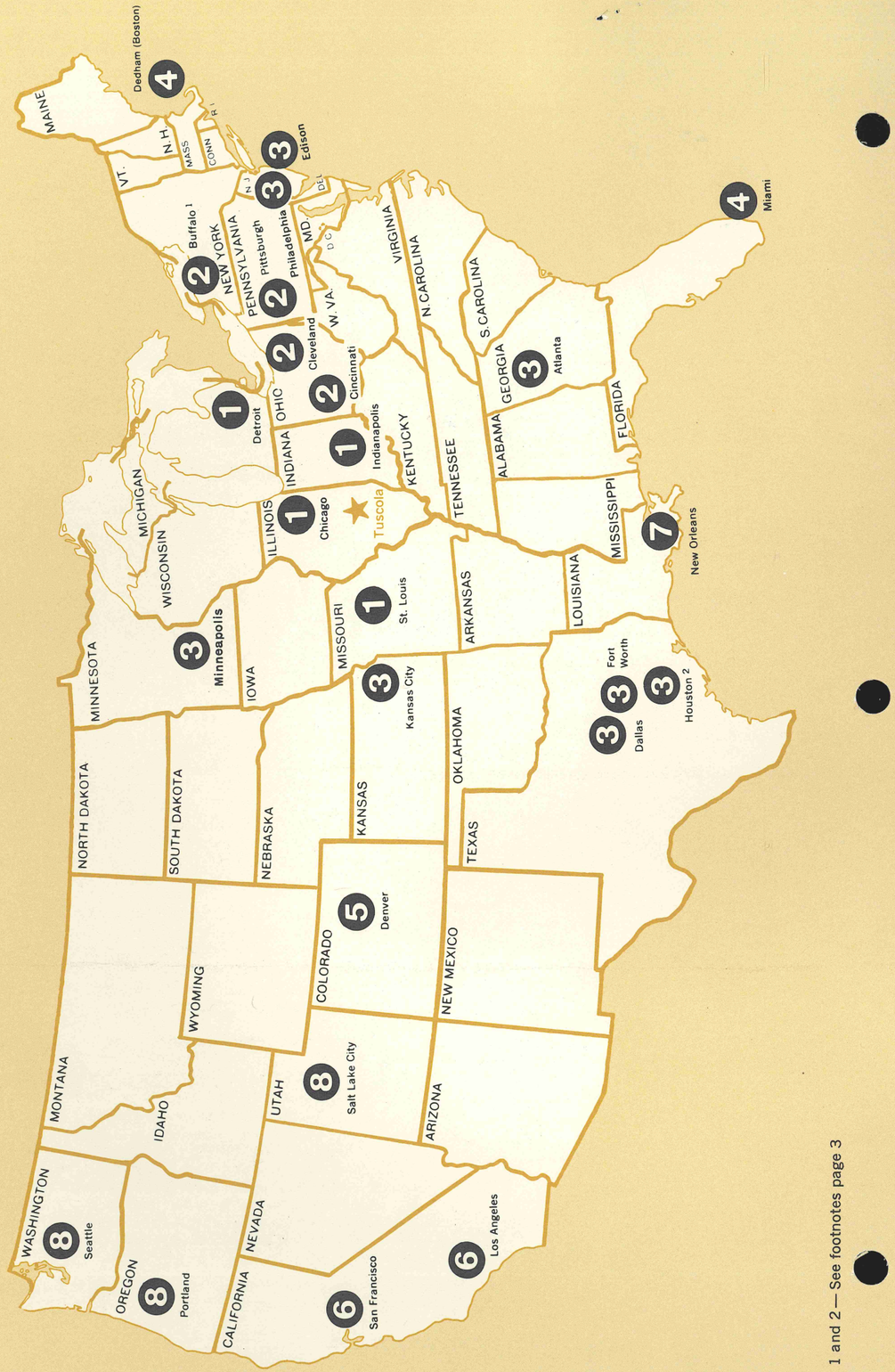
Questions regarding orders — The local Cabot sales office or representative will be glad to answer questions about orders handled by that particular office. A master shipping control record is also maintained by the Customer Service Department, Boston, Mass. office.

Technical questions — Cabot maintains a technical service laboratory with personnel qualified to answer application questions. CAB-O-SIL sales representatives are also technically trained, but spend a major portion of their time in the field. If your local representative is out, or if urgent problems arise, please call Technical Service Manager, Boston, Mass. (617) 423-6000.

Terms: Net 30 days — subject to change without notice. Orders adjusted to correspond with standard weight per bag.

CABOT® CABOT CORPORATION 125 HIGH STREET, BOSTON, MASSACHUSETTS 02110

WAREHOUSE LOCATIONS



1 and 2 — See footnotes page 3

GRADES OF CAB-O-SIL® and price per lb.

WAREHOUSE LOCATION	QUANTITY 10-lb. bags	M-5 MS-5	H-5	HS-5[3]	EH-5	QUANTITY 20-lb. bags	MS-7	M-7 M-7D[3]	QUANTITY 25-lb. bags	L-5
1	10- 30 lbs.	$1.31	$1.41	$1.44	$1.48	20- 60 lbs.	$1.31	$1.29	25- 75 lbs.	$1.31
	40- 190 lbs.	.97	1.05	1.08	1.14	80- 180 lbs.	.97	.95	100- 175 lbs.	1.04
	200- 590 lbs.	.83	.91	.94	1.00	200- 580 lbs.	.83	.81	200- 575 lbs.	.90
	600-1990 lbs.	.79	.87	.90	.96	600-1980 lbs.	.79	.77	600- 1975 lbs.	.86
	2000-5990 lbs.	.73	.81	.84	.90	2000-9980 lbs.	.73	.71	2000-11,975 lbs.	.80
2[1]	10- 30 lbs.	$1.31	$1.41	$1.44	$1.48	20- 60 lbs.	$1.31	$1.29	25- 75 lbs.	$1.31
	40- 190 lbs.	.98	1.06	1.09	1.15	80- 180 lbs.	.98	.96	100- 175 lbs.	1.05
	200- 590 lbs.	.84	.92	.95	1.01	200- 580 lbs.	.84	.82	200- 575 lbs.	.91
	600-1990 lbs.	.80	.88	.91	.97	600-1980 lbs.	.80	.78	600- 1975 lbs.	.87
	2000-5990 lbs.	.74	.82	.85	.91	2000-9980 lbs.	.74	.72	2000-11,975 lbs.	.81
X 3[2]	10- 30 lbs.	$1.31	$1.41	$1.44	$1.48	20- 60 lbs.	$1.31	$1.29	25- 75 lbs.	$1.31
	40- 190 lbs.	.99	1.07	1.10	1.16	80- 180 lbs.	.99	.97	100- 175 lbs.	1.06
	200- 590 lbs.	.85	.93	.96	1.02	200- 580 lbs.	.85	.83	200- 575 lbs.	.92
	600-1990 lbs.	.81	.89	.92	.98	600-1980 lbs.	.81	.79	600- 1975 lbs.	.88
	2000-5990 lbs.	.75	.83	.86	.92	2000-9980 lbs.	.75	.73	2000-11,975 lbs.	.82
4	10- 30 lbs.	$1.31	$1.41	$1.44	$1.48	20- 60 lbs.	$1.31	$1.29	25- 75 lbs.	$1.31
	40- 190 lbs.	1.00	1.08	1.11	1.17	80- 180 lbs.	1.00	.98	100- 175 lbs.	1.07
	200- 590 lbs.	.86	.94	.97	1.03	200- 580 lbs.	.86	.84	200- 575 lbs.	.93
	600-1990 lbs.	.82	.90	.93	.99	600-1980 lbs.	.82	.80	600- 1975 lbs.	.89
	2000-5990 lbs.	.76	.84	.87	.93	2000-9980 lbs.	.76	.74	2000-11,975 lbs.	.83
5	10- 30 lbs.	$1.39	$1.47	$1.50	$1.56	20- 60 lbs.	$1.39	$1.37	25- 75 lbs.	$1.39
	40- 190 lbs.	1.02	1.10	1.13	1.19	80- 180 lbs.	1.02	1.00	100- 175 lbs.	1.09
	200- 590 lbs.	.88	.96	.99	1.05	200- 580 lbs.	.88	.86	200- 575 lbs.	.95
	600-1990 lbs.	.84	.92	.95	1.01	600-1980 lbs.	.84	.82	600- 1975 lbs.	.91
	2000-5990 lbs.	.78	.86	.89	.95	2000-9980 lbs.	.78	.76	2000-11,975 lbs.	.85
6	10- 30 lbs.	$1.31	$1.41	$1.44	$1.48	20- 60 lbs.	$1.31	$1.29	25- 75 lbs.	$1.31
	40- 190 lbs.	1.04	1.12	1.15	1.21	80- 180 lbs.	1.04	1.02	100- 175 lbs.	1.11
	200- 590 lbs.	.90	.98	1.01	1.07	200- 580 lbs.	.90	.88	200- 575 lbs.	.97
	600-1990 lbs.	.86	.94	.97	1.03	600-1980 lbs.	.86	.84	600- 1975 lbs.	.93
	2000-5990 lbs.	.80	.88	.91	.97	2000-9980 lbs.	.80	.78	2000-11,975 lbs.	.87
7	10- 30 lbs.	$1.31	.....	.....	.....	.....	.....	.....	.....	.....
	40- 190 lbs.	1.01	.....	.....	.....	.....	.....	.....	.....	.....
	200- 590 lbs.	.87	.....	.....	.....	.....	.....	.....	.....	.....
	600-1990 lbs.	.85	.....	.....	.....	.....	.....	.....	.....	.....
	2000-5990 lbs.	.79	.....	.....	.....	.....	.....	.....	.....	.....
8	10- 30 lbs.	$1.36	$1.44	$1.47	$1.53	20- 60 lbs.	$1.36	$1.34	25- 75 lbs.	$1.36
	40- 190 lbs.	1.06	1.14	1.17	1.23	80- 180 lbs.	1.06	1.04	100- 175 lbs.	1.13
	200- 590 lbs.	.92	1.00	1.03	1.09	200- 580 lbs.	.92	.90	200- 575 lbs.	.99
	600-1990 lbs.	.88	.96	.99	1.05	600-1980 lbs.	.88	.86	600- 1975 lbs.	.95
	2000-5990 lbs.	.82	.90	.93	.99	2000-9980 lbs.	.82	.80	2000-11,975 lbs.	.89
★TUSCOLA ILL. PLANT	Truckload (6,000 lbs.) or carload quantity	.70	.78	.81	.87	Truckload (10,000 lbs.) or carload quantity	.70	.68	Truckload (12,000 lbs.) or carload quantity	.77

1. Buffalo — Due to extra freight add 0.5 cents/lb. to all prices listed, except 10-30 lb. quantities.
2. Houston — Due to extra freight add 0.2 cents/lb. to all prices listed.
3. Grades HS-5 and M-7D are available only in polyethylene overslips on warehouse shipments.
4. Grades MS-75 0.71/lb.; S-17 0.86/lb. in carload or truckload quantities F.O.B. Tuscola, Illinois.

NOTE: For polyethylene overslips add 2.5¢/lb. for 10-lb. bags; 1.25¢/lb. 20-lb. bags; 1.0¢/lb. 25-lb. bags.

Mr. Vadnagara requests additional information as to the capacitance of the test circuit for the current-limiting fuses. The normal test circuit would have an inherent shunt capacitance of several thousand picofarads, the exact amount depending on whether high-voltage transformers with capacitance graded bushings, actual length of buswork, and impedance loading were used. This capacitance would be in the range of normal overhead distribution.

Typical installations using underground cable would have a shunt capacitance of much higher value. These values could range from 0.1 to 0.5 μF. Since the normal test setup does not utilize any shunt capacitance of these values, a special test was made to determine whether it would be an appreciable factor. One size (15.5 kV 10 amperes) NX fuse was tested on a circuit with an available fault current of 12 kA at the fuse design voltage. A shunt capacitance (in addition to the normal circuit capacitance) was varied from 0.075 to 0.53 μF during the test sequence. The peak arc voltage was found to be slightly higher (2.5 to 5 percent) with the larger shunt capacitance value than the maximum obtained with no added shunt capacitance. I would attribute this to a slight interaction between the circuit inductance and the shunt capacitance when the fuse element melts and introduces a rapid resistance into the circuit; but the same resistance quickly dampens any oscillatory effects and prevents higher overshoot of the voltage.

Mr. Bronikowski's supposition regarding the use of ribbon-element NX fuses at lower circuit voltages with a corresponding reduction of maximum arc voltage is correct. Also, with this type of element, the maximum arc voltage remains independent of the fault current. This characteristic permits more versatility of application as Mr. Bronikowski mentions, especially as related to coordination with lightning arresters.

Testing EHV Station Insulation for Performance in Contaminated Conditions

JAMES D. M. PHELPS, MEMBER, IEEE, JAMES B. OWENS, SENIOR MEMBER, IEEE, AND AREM FOTI, SENIOR MEMBER, IEEE

Abstract—This technical paper deals with two phases of wet testing of EHV station insulators; one for conventional rainfall tests with prescribed rate of precipitation and water resistivity and the other for artificial contamination or pollution tests under wet conditions. The authors recommend a change in USA Standards for rate of precipitation and resistivity of water and offer supporting test data confirming the ability to distinguish between satisfactory and unsatisfactory insulator designs as a result of employing their new proposal. They also offer a proposed contamination test procedure which is convenient to use, which gives reproducible results, and which is sufficiently flexible for use in varying the severity of the applied artificial contaminant according to user requirements. The artificial contamination, or pollution, test may be used in rating insulator designs concerning performance under contaminated and wet conditions.

Introduction

INSULATION systems for outdoor stations have traditionally been designed using stacking apparatus insulators. Porcelain elements with appropriate joining hardware have been assembled into columns to provide adequate height and insulation performance. When insulation systems have been designed for extra high voltage (EHV) stations rated 345 kV and higher, it has been observed that incremental increases in the height of insulator columns do not produce a corresponding or proportionate increase in the insulating value achieved. This is particularly true when insulation is subjected to long-duration switching surge voltages. Extra care in testing and evaluation of test information has been required to insure the desired reliability of EHV station insulation performance.

In the design of 500- and 765-kV stations for operation in coastal or industrial environments, it is particularly important that insulation performance be evaluated with a proper simulation of the variety of conditions that will exist in service. Consideration must be given to the effects of rain, fog, and moisture condensation on clean and contaminated insulator surfaces.

Tests have been conducted leading to the establishment of new performance criteria for wet testing to evaluate insulation performance during rainfall conditions. In addition, work has been done to develop a technique for the simulation of heavy surface contamination wetted by fog or mist. The work was undertaken because there was no recognized system of evaluation from which reliable and repeatable results could be obtained and related to field experience.

Wet or Rain Testing

The current standards of the U.S.A. Standards Institute[1] specify that outdoor station apparatus insulators be subjected to a wet test using water of 17 800 ohm-cm resistivity falling at a rate which will allow an accumulation of 5.08 mm/min. The standards of the International Electrotechnical Commission (IEC)[2] specify that wet testing be conducted with 9000–11 000 ohm-cm water and a rainfall rate of 3 mm/min. These are exceedingly heavy rates, corresponding to an accumulation of 7–12 inches per hour or 17–29 feet per day. Such rates of rainfall rarely, if ever, occur in outdoor station operating environments.

The resistivity of the water specified in the U.S.A. standards is substantially higher than the resistivity of rain water that has fallen through normal city or industrial atmospheres during the early portion of rain incidents.[3] IEC requirements more closely

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J. D. M. Phelps is with the American Electric Power Service Corporation, Canton, Ohio.

J. B. Owens and A. Foti are with the I-T-E Circuit Breaker Company, Greensburg, Pa. 15601

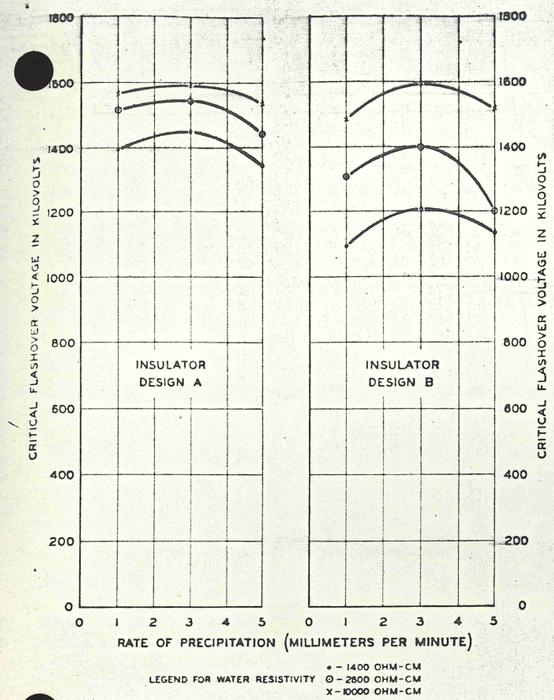

Fig. 1. Influence of rainfall rate on critical (50 percent probability) flashover voltage for positive polarity switching surge, 181-inch insulators.

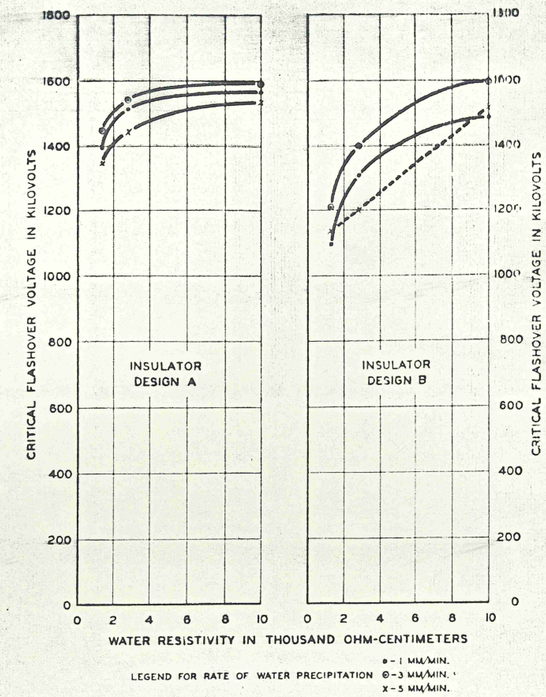

Fig. 2. Influence of water resistivity on critical (50 percent probability) flashover voltage for positive polarity switching surge, 181-inch insulators.

TABLE I

WET SWITCHING SURGE TESTS ON 181-INCH INSULATORS

Rainfall Rate, mm/min	Rainfall Resistivity, kΩ·cm	Design A +CFO	Design A 2σ +WS	Design B +CFO	Design B 2σ +WS
5	17.0	1525	1330	1555	1390
5	10.0	1535	1310	1520	1350
5	2.8	1445	1305	1200	1080
5	1.4	1345	1120	1135	976
3	10.0	1590	1360	1595	1360
3	2.8	1545	1360	1400	1275
3	1.3	1440	1330	1210	1045
1	10.0	1565	1315	1485*	1330*
1	2.8	1515	1405	1305	1035
1	1.4	1395	1280	1095	995

Conditions: Waveshape 145/4000 μs, insulators 20 feet above ground plane.

* Tests with negative impulses gave lower values for this case. All other negative critical flashovers (CFO) and WS's were higher or equal.

represent average values recorded in the U.S.A., but large deviations occur in actual system operation.

It was decided in this program to test two designs of 181-inch high EHV station insulators with switching surge impulses while subjected to a wide variety of water rates and resistivities. The tests were conducted and the data evaluated in accordance with an IEEE technical report.[4] The principal test results are recorded in Table I. Figs. 1 and 2 show the effect of varying either water rate or resistivity. It was observed that the differences in performance in both insulator designs was small when the water rate was varied from 5 mm/min down to 1 mm/min. However, the insulator flashover voltages of design B deteriorated considerably with reductions in rainfall resistivity. Insulator design A showed a smaller reduction than that exhibited by design B. This contrasted markedly to the performance of the two designs when subjected to either U.S.A. or IEC standard conditions. In the latter case, no difference in the performance of the two designs was detected. Design A also had a higher withstand when subjected to a contamination test described later.

CONTAMINATION TESTING

Outdoor station insulation can accumulate industrial or natural solid deposits that greatly reduce the insulation value during periods of fog and moisture condensation. Many investigators have done work to provide a laboratory simulation of this condition. Satisfactory results have been achieved with mixtures of China clay and sodium chloride.[5] Insulators so contaminated and erected in fog chambers exhibit flashover performance similar to that observed in station operation. As far as it could be determined, however, no tests had been devised which could 1) be varied to correlate with field conditions, and 2) be conducted without elaborate laboratory facilities.

Determination of Standard Contaminant

To determine a suitable contaminant for the evaluation of 500- and 765-kV insulators, it was decided to build upon the known performance of 345-kV, 1050-kV basic insulation level (BIL),

TABLE II

DETERMINATION OF STANDARD CONTAMINATION ON 90-INCH HIGH, 345-KV INSULATORS

Insulator Sample	Fog Exposure Time No Voltage, minutes	Rapid Rise Flashover, kV	50-kV Stress Time, minutes	Leakage Current at 50 kV, mA	210-kV Stress Time, minutes	Power Frequency Flashover, kV
1			75		60	263
1			75	1.86	60	266
2			75	1.0	60	234
2			30	1.0	60	256
2			90	1.0	60	270
3			90	2.2	60	300
3	10	263	5	2.0	60	235
3	10	252	5	1.0	60	240
3	10	262	5	1.5	60	283
					Average value	261

Conditions:
Contaminant: China Clay, Bentonite. Thickness: 7 mg/cm². Resistivity: 4400 ohm-cm when mixed (Clay, 30.7 percent; Bentonite, 0.2 percent; Water, 69.1 percent).
Fog Resistivity: 10 000 ohm-cm.
Chamber: 52 × 56 × 46 feet high.
Insulator 20 feet above ground plane.

198-inch leakage distance, station post insulators. Such insulators have provided satisfactory performance when subjected to industrial and power plant contamination of American Electric Power properties in the Ohio River Valley.

It was decided that a contaminant to represent the field contamination would necessarily provide the following results on insulators tested in a fog chamber:

1) Insulators to withstand the maximum line-to-ground operating voltage of 210 kV for at least one hour.

2) Range of power frequency flashover not to exceed 300–220 kV.

Testing Procedure

The following procedure was evolved. Insulators were contaminated by spraying with a "standard" mixture having the following composition:

Ingredient	Percentage by Weight
China clay	30.7
Bentonite	0.2
Distilled water	69.1
NaCl	As required.

Insulators to be tested were sprayed on all surfaces with this mixture and the resulting coating allowed to dry. The insulators were then assembled in a fog chamber so that the contaminant became thoroughly wet prior to measuring the power frequency withstand and flashover voltages.

Two variables were found to affect the insulator performance. The first variable was the resistivity of the liquid contaminant mixture. It was found that various China clays contained a variety of soluble salts so that the volume resistivity of the resulting mixture varied widely. It became necessary to determine a source of clay that was relatively free from soluble salts so that small quantities of NaCl could be added to the liquid contaminant mixture to control the resistivity.

TABLE III

FOG CONTAMINATION TESTS ON 181-INCH INSULATORS

Insulator Design	Sample	Power Frequency, applied kV	Time to Flashover, minutes
A	1	465	60, withstand
A	2	465	60, withstand
A	3	465	60, withstand
B	1	465	13
B	2	465	3
B	3	420	10
B	3A	420	16

Conditions:
Contaminant: China Clay, Bentonite. Thickness: 7 mg/cm². Resistivity: 4400 ohm-cm when mixed (Clay, 30.7 percent; Bentonite, 0.2 percent; Water, 69.1 percent).
Fog Resistivity: 10 000 ohm-cm.
Chamber: 52 × 56 × 46 feet high.
Insulators 156 inches above ground plane.

TABLE IV

WET CONTAMINATION TESTS ON 181-INCH INSULATORS

Power Frequency Flashover Measurements at 10-Minute Intervals While Drying		
Drying Time, minutes	Design A Flashover, kV	Design B Flashover, kV
0	740	470
10	655	595
20	1025	715
30	1005	870
40	1045	920
50		965
60		975

Conditions:
Contaminant: China Clay, Bentonite. Thickness: 7 mg/cm². Resistivity: 4400 ohm-cm when mixed (Clay, 30.7 percent; Bentonite, 0.2 percent; Water, 69.1 percent).
Insulator 20 feet above ground plane.
Spray of 10 000 ohm-cm applied to thoroughly wet contaminant.

The second variable influencing insulator performance was the thickness of the contaminant layer. A uniform thickness of contaminant layer producing a dry solid contaminant weighing 7 mg/cm² was selected for preliminary insulator evaluation.

The 1050 BIL station post insulators coated with a standard mixture were found to meet the 210-kV, 300-kV maximum flashover criterion when contaminant resistivity was 4400 ohm-cm with a 7 mg/cm² deposit. Table II shows the results obtained when three similar insulator columns were contaminated with this mixture, the mixture allowed to dry, and assembled in a fog chamber for complete layer rewetting. It will be noted that all nine tests resulted in a one hour withstand determination at 210 kV, followed by a rapid rise flashover voltage equal to or less than 300 kV. The average flashover voltage value for nine tests was 261 kV.

During these tests, it was observed that erroneous values could be recorded if the contaminant layer was not thoroughly wet from its exposure to the fog. With the relatively thick contamination,

TABLE V

RELATIONSHIP BETWEEN FLASHOVER VOLTAGE AND CONTAMINATION THICKNESS ON 30-INCH STATION POST INSULATOR ELEMENTS

Sample Number	Liquid Contaminant Resistivity, ohm-cm	Dry Deposit, mg/cm²	Spray Water Resistivity, ohm-cm	Flashover, kV Test Number 1	2	3	4	5	6	7	8	9	Average
1	10 400	22.3	10 000	134	115	115	116	114	117				110
2A	4500	11.0	10 000	122	122	126	106	114	116	106			116
2B	4500	7.08	10 000	142	127	130	134	137	129				133
3	1650	3.07	10 000	149	134	129	140.5	135	143				138
4A	380	0.77	10 000	165.5	127	143	135	152.5	175				150
5B	155	0.203	10 000	177	152.5	167	152.5	127	125	146			150
1	10 400	22.3	115 000	160.5	158	117	152.5	124	131	125	127	131	136
2A	4500	11.0	115 000	172	152.5	136	142	156	127	136			146
2B	4500	7.08	100 000	145	146	151	151	138	148				147
5A	155	0.144	115 000	230	228	193	185.5	182	183	191	194		198

TABLE VI

RELATIONSHIP BETWEEN WITHSTAND VOLTAGE AND CONTAMINANT RESISTIVITY

Ratio of Contaminant Resistivity Thickness Variable 30-inch Station Post Insulator Elements

Insulator Sample Number	Liquid Contaminant Resistivity, ohm-cm	Dry Deposit, mg/cm²	Voltage Level, kV	Number of 15-Minute Withstands
1	10 400	23.6	54	6
2A	4500	7.08	63	6
2B	4500	7.15	63	6
3	155	0.68	122	6

Conditions:

Contaminant: Water, 69.1 percent; Kaolloid, 30.7 percent; Bentonite, 0.2 percent; Salt as required.
Mounting: ASA insulator test mounting.
Wet Spray: 10 000 ohm-cm water sprayed to thoroughly wet contaminant.

TABLE VII

RELATIONSHIP BETWEEN FLASHOVER VOLTAGE AND DRYING TIME FOR 30-INCH STATION POST INSULATOR ELEMENTS

Drying Time, minutes	Sample 1, 4500 ohm-cm Contaminant, Flashover, kV	Sample 2, 380 ohm-cm Contaminant, Flashover, kV
0	129	120
5	112	114
10	128	96
15	122	99
20	149	109
25	171	133
30	184	151
35	217	154
40	222	167
45	257	170
50	255	183
55	258	206
60		236
65		293
70		274

Conditions:

Contaminant (Sample 1): Resistivity: 4500 ohm-cm. Thickness: 7.08 mg/cm². Mixture: Water, 69.1 percent; Kaolloid, 30.7 percent; Bentonite, 0.2 percent; Salt, none.
Contaminant (Sample 2): Resistivity: 380 ohm-cm. Thickness: 1.21 mg/cm². Mixture: Water, 69.02 percent; Kaolloid, 30.66 percent; Bentonite, 0.20 percent; Salt, 0.12 percent.
Mounting: ASA insulator test mounting.
Wet Spray: 10 000 ohm-cm water sprayed to thoroughly wet contaminant.

this required fog exposure times in excess of one hour. It was found that this time could be substantially shortened and valid results observed if the contaminant layer was presprayed with water having the same resistivity as the fog water, using a spray gun producing a fine mist.

Fog-Contamination Tests on EHV Insulators

The standard contamination testing procedure developed on 345-kV insulators was used to evaluate two proposed designs for 765-kV station service. For this evaluation, the criterion of satisfactory performance was the ability of an insulator to withstand an applied voltage of 465 kV for 60 minutes while the unit was contaminated and maintained in a wet condition in a fog chamber. The results of this test for two insulator designs are shown in Table III. Three samples of the design A insulator were each able to withstand an applied voltage of 465 kV for 60 minutes without flashover. Four tests on the design B insulators indicated their inability to withstand a voltage as low as 420 kV.

Wet-Contamination Tests

In the testing program, laboratory limitations made it impossible to determine the flashover voltages of contaminated insulators in the fog chamber. To measure this quantity, one sample of each of the insulator designs was contaminated and erected in a high-voltage testing chamber. The contaminant layer was thoroughly wetted by spraying with 10 000 ohm-cm water. The flashover voltages taken at 10 minute intervals, while the insulators were drying, are shown in Table IV. These results indicate a distinct superiority for the design A insulator. It should be noted, however, that the flashover voltage for this insulator was observed to decrease during the first 10 minutes of drying.

Supplemental Tests on 30-inch Station Post Insulators

In addition to the tests conducted on EHV insulators, supplemental tests were performed on 30-inch high, 14-inch outside

diameter, 66-inch leakage distance, station post insulator elements. These tests were divided into three portions. The first series observed variations in flashover performance with variations in thickness and resistivity of solid contaminant deposit. To conduct this investigation, a number of insulator samples were coated with the standard contaminant described before with the resistivity adjusted by the addition of NaCl. A range of resistivities from 10 400 to 155 ohm-cm was investigated. Contaminant thickness was kept approximately proportional to the volume resistivity with the ratio of volume resistivity in ohm-cm to the dry deposit weight in mg/cm² within 1080 to 280. In this way, high-resistivity contaminant was put on in very thick coatings and low-resistivity contaminant was put on in very thin coatings.

The contaminated samples were arranged for flashover testing and the contaminant thoroughly wetted by a fine mist spray of either 100 000, 115 000, or 10 000 ohm-cm of water. The power frequency flashover test results are recorded in Table V. It was observed from these data and observations during the tests that best results were obtained within the following constraints:

1) Spray water resistivity constant, maximum 10 000 ohm-cm
2) Resistivity/(mg/cm²) ratio 410–640
3) Weight of dry contaminant deposited, 2–12 mg/cm².

Ratio 2) will vary depending on the severity of contamination to be simulated. The limits of 3) were selected because great difficulty exists in maintaining very thick coatings during the wetting period, and also, great experimental difficulty is experienced in providing very thin coatings of uniform thickness.

Several supplemental tests were made to determine how the resistivity/(mg/cm²) ratio affects withstand. Results are summarized in Table VI. Comparison of Tables VI, II, and V shows that withstand kV per stacking unit is reasonably constant while flashover kV per stacking unit decreases with increasing stack height. This phenomenon needs further study with various insulator designs before any general conclusions can be drawn.

A third series of supplemental tests was conducted to observe the influence of drying time on flashover voltage on 30-inch station post insulator elements. The results of these tests are recorded in Table VII. It is noted here that the flashover voltage decreased in excess of 20 percent from the time the insulator was thoroughly wet to the point where the lowest flashover voltage was observed with the insulator partially dry. Further study is indicated, especially to determine the need for including a drying period as a part of a withstand test. Although not mentioned in Table III, design A insulators withstood 465 kV during drying periods up to 30 minutes after fog was discontinued and allowed to dissipate.

Conclusion

The most serious fault to be found with present wet test standards is that they fail to discriminate between satisfactory and unsatisfactory designs. It is recommended that consideration be given to a wet test using a rainfall which will accumulate at a rate of 1 mm/min and which has a volume resistivity in the range of 2500–3000 ohm-cm.

A contamination test has been devised which is convenient to use and gives consistent results. Means are provided to permit alteration of the test to give various degrees of severity according to user requirements.

Data obtained during the tests reported in this paper are not sufficiently complete to permit substituting flashover tests for withstand tests.

Acknowledgment

The authors gratefully acknowledge the outstanding contributions to this program of W. J. Lyon of American Electric Power Service Corporation, F. H. Moser of the I-T-E Circuit Breaker Company, and the staff of the C.E.S.I. Laboratory in Milan, Italy.

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Discussion

Fred Chambers (Tennessee Valley Authority, Chattanooga, Tenn.): This paper relates test data that has been obtained in a very important area to electric system engineers. One of the toughest problems encountered in EHV design concerns satisfactory insulation coordination in substations. This problem is particularly aggravated by the presence of contaminants that can be deposited on the insulators and bushings.

The paper provides switching surge critical flashovers and withstand values for contaminated insulator stacks that are 181 inches high, those which are, presumably, normally used for the 700–765-kV class facilities. If similar tests have been run for insulator stacks of the order of 145 to 152-inches high, those usually chosen for the 500–550-kV class, it would be most interesting to have this information made known.

The dielectric characteristics of insulator columns depend to a considerable degree on both the total leakage distance and on the configuration of the skirt arrangement that makes up the total leakage distance. There are three general types of bus support insulator configurations, namely, the conventional bus stacking units that are each 14½ inches high and are characterized by a major shell arrangement; the various types of hollow- and solid-post insulators that generally have the leakage distance made up of relatively small skirts; and the cone type of structure developed in Europe that is now finding application in the U. S. Apparently the authors prefer not to identify their design A and design B in the paper; however, we wonder if they could reveal either the leakage distances of each design or the ratio of leakage distances. It is apparent that neither design is made up of the conventional 14½-inch bus stacking units. It would therefore be of interest to know if similar tests have been made using 14½-inch bus stacking units and if this information will be available.

It is hoped that the authors will continue their testing in this area. This discusser is located in an area where there are occasional heavy rainstorms, usually of short duration, and it would be of considerable interest to have information on the 60-cycle performance of contaminated insulators under such conditions, or insulator performance after a long dry period when a light rain or fog is applied.

The TVA system experienced a flashover of a 161-kV transformer bushing which occurred when a light rain began freezing on the

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relatively lightly contaminated surface. In this instance the transformer bushing was vertically mounted and therefore similar to a porcelain bus support.

W. A. McNeill (Doulton Industrial Porcelains Ltd., London, England): The authors have made a useful contribution to the study of wet flashover under varying rainfall conditions and also of flashover and reproducible artificial surface contamination. The ultimate value of these studies will, of course, be determined by the extent to which the observed absolute laboratory measurements can be used to forecast the service performance of new insulator designs.

The potential value of the artificial contamination technique is amply demonstrated by the results given in Tables III and IV where the superior performance under pollution of design A is clearly demonstrated, even though the differences in performance on the standardized wet flashover tests are marginal. It would be most interesting to employ these laboratory contamination techniques to compare with the tests conducted at the Brighton Testing Station in England, where very satisfactory performance has been obtained under combined saline and fly-ash pollution with Multicone insulators at 400 and 650 kV. The former, having an overall height of 151 inches, a leakage path of about 430 inches, and operating on a line voltage of 400 kV, has given a favorable performance compared to the cap and pin insulators made up into a pedestal post 171 inches high. As practical evidence of the performance, in a country notorious for its difficult atmospheric conditions, more than 5000 of the 400 kV posts have been ordered, covering about half the total 400 kV network requirements. The successful performance is attributed to the form and distribution of the creepage path, which is proportionately greater at the line end of the insulator, and to the reduction in the amount of intermediate metalwork.

Evidence such as that presented in the paper and correlated with service results could be most valuable in formulating a form of test under artificial pollution conditions as a means of discriminating between insulator designs at an earlier stage than is currently possible by means of extended field trials. Reference may be made to an earlier paper on the same subject.[6]

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Manuscript received February 13, 1967.

J. H. Moran (Lapp Insulator Company, Inc., Le Roy, N. Y.): The authors are to be commended for attempting to produce a test procedure for evaluating the effects of contamination. We have done considerable work with the method described and find it to be as reliable for repeating data from test to test as any similar test. However, the authors list only two variables, 1) the resistivity of the contaminant mixture and, 2) the thickness of the contaminant layer as affecting the insulator performance. The effect of such factors in the clay, such as particle size, distribution of particle size, the chemical composition of the soluble salts remaining in the clay, and the pH of the clay mixture, are all very important. Also such intangibles as the ability of the contaminant to stick to the insulator and the amount of water which the contaminant can hold without running or flaking off the insulator produce widely variable results.

It would seem that the unspecified properties of the materials required for the standard mixture are of such magnitude as to produce grave doubts as to the validity of such a contaminated test from time to time and place to place.

Further, a great dependence is placed on the standard mixture of 30.7 percent China clay, 0.2 percent Bentonite, and 69.1 percent distilled water. In view of the great variation in the many characteristics of China clay and Bentonite, both physical and chemical, the specification of such precise numbers seems unrealistic.

Manuscript received February 13, 1967.

R. W. Harmon (Ohio Brass Company, Barberton, Ohio): The study of contamination is an awesome task, yet it is a task which demands an aggressive attack such as this if improved service reliability is to be reconciled with spreading pollution.

The nature of contamination, which is probably as diverse as any problem in the power industry, indicates that means for satisfactory test and evaluation will be found only after diligent and probably exhausting work. The tests proposed in this paper are realistic and have much to recommend them for further pursual.

The reduced rate of higher conductivity rainfall goes a long way to improve the oft-maligned IEEE standard rain conditions. This is the same precipitation rate and resistivity that we have used for switching surge tests for some time. We endorse the authors' recommendation that appropriate standardization committees consider new parameters.

The proposed contamination test holds much promise for development into a practical test method. Unlike many of the tests which have been used recently, flashovers are precipitated from reasonable magnitude current surges. Our experience with this test indicates it does not share the rather serious flaw of unrealistically high current surging that is so prevalent in artificial contamination tests. In this regard and in other preflashover behavior, the flashover mechanism appears to do a good job of simulating natural service flashovers. The test, at least for contamination testing, is not overly difficult.

As with any new test in which a single technique attempts to duplicate a bewildering array of service conditions, much cautious work must be done before general adoption can be recommended. We believe this test should be pursued, along with others, for refinement into a general test. It appears to satisfy the basic requirements of reproducibility and reasonably accurate representation of service flashovers in a practical test technique.

Manuscript received February 23, 1967.

E. C. Sakshaug (General Electric Company, Pittsfield, Mass.): A few of the points made by the authors are not entirely clear. A set of constraints is listed including the ratio of volume resistivity of the liquid contaminant to the thickness of coating in mg/cm². It is stated that this ratio should fall between 410 and 640 for best results. Two samples listed in Table V, 5A and 5B, had ratios of 1075 and 763, respectively. However, the results given for these two samples appear to line up with the results for samples tested within the specified range.

Another aspect on which comment by the authors is requested is that the first test point for each sample shown in Table V is almost invariably higher than the other test points. One possible explanation is that the samples were not thoroughly wet when the first tests were made.

Similarly, the data given in Table VII indicate that flashover values decrease during the initial portion of the drying period. Is it possible, however, that the samples were really wet during this time and the results reflect variability in the wet condition rather than a decrease in flashover resulting from partial drying?

Manuscript received February 24, 1967.

G. Carrara and **L. Zaffanella** (C.E.S.I., Milan, Italy): The authors are to be commended for the considerable amount of switching impulse wet tests they performed.

We are involved with the work of the Working Group on Measuring Technique of CIGRE Study Committee 8, which is examining carefully what steps are to be taken when normalizing switching impulse wet tests.

Existing standards for power frequency wet tests require the rain to have characteristics which are impractical to obtain, not realistic, and on which narrow tolerances are imposed.

Manuscript received February 27, 1967.

The work presented by the authors shows that noticeable variations in test results can *not* be attributed to variations of the order of 30 to 50 percent of rain intensity, or resistivity; therefore the present tolerances (of ± 10 percent) may be drastically increased.

Difficulties in wet testing are also found when trying to obtain a 45-degree rain, so that several testing stations perform tests with the water falling practically vertically, It would be extremely helpful, to increase the tolerances on the angle also, to know the influence of its variation.

Two more points seem to be worthy of study, namely the effect of rain on the standard deviation and the comparison between results obtained under artificial and under natural rain.

We agree with the author that, at the present state of the art of contamination testing, comparing the high-voltage insulators with a lower-voltage insulator which behaved correctly under the same contamination under which the high-voltage insulators are to be installed, is a sound approach.

Such a procedure, however, will be of very difficult, if not impossible, to standardize, since not many users will agree on "the insulator" to be commonly accepted as comparison sample. The method, in addition, does not discriminate between two insulators which both withstand the test.

A second point refers to the validity of the results obtained when raising the voltage up to flashover. The phenomenon is such that it is completely changed by voltage variations. We therefore are in favor of performing successive withstand tests (each about one hour long) at increasing contamination severity and constant voltage close to operating voltage, rather than relying on flashover tests performed at constant contamination severity.

In our opinion the withstand test must cover all the three different wetting conditions, namely: the *wetting*, *steady fog*, and *drying out* periods.

When speaking of "contamination severity" we mean that the contaminating and wetting procedure must be such that each test may be associated with a well-defined, easily measurable, quantity, which represents the "degree" of contamination (in a way similar to that used for earthquakes or seastorms).

To represent such a quantity, the authors suggested the ratio between the liquid contaminant resistivity and the dry deposit surface density. We would like to know if the authors tried to use the "equivalent salt deposit density" which is used by many authors, and, if not, why. (Equivalent salt deposit density is defined as the salt quantity that, diluted in a given amount of distilled water, gives the same volume resistivity as that given by the dry deposit, scraped from the unit area of a representative surface of the insulator and diluted in the same quantity of water.)

J. D. M. Phelps, J. B. Owens, and Arem Foti: We are pleased to give recognition to the discussers and offer the following answering statements.

To Mr. Chambers we would reply that the bulk of our investigations applied to 765-kV insulators because 765 kV was primarily the system operating voltage for which the investigation was undertaken. The test method described is equally applicable to 500-kV insulators. Insulator stacks using 14½-inch high stacking units were not tested because their use in EHV is very small. Insulator A of the paper had a leakage distance of 482 inches; insulator B had 432 inches.

Manuscript received June 30, 1967.

Coincidentally W. A. McNeill's discussion imparts some information in which Mr. Chambers is interested. This concerns relative performance between 151-inch high Multicone insulators—the height that would normally be used for 500-kV service—and the stacking 14½ inch cap and pin insulators. Mr. McNeill's experience of superior performance with the Multicone insulator essentially parallels ours.

A review of Mr. Moran's comments reveals an implication of testing difficulties arising from intangibles. Apparently, we were more fortunate than he. We would like to advise that it was standard practice in our contamination testing program to thoroughly wash the insulators with a detergent prior to applying the contaminant. It is believed that this precautionary measure enhances the ability of the contaminant to adhere to the insulator. The two variables (resistivity of the contaminant mixture and the thickness of the contaminant layer) were found to have the greatest effect on insulator performance. Consequently, they were the two variables stressed in the paper. We are sorry that Mr. Moran takes exception to the precise proportion of ingredients of the "standard" contaminant mixture. The authors elected to use the same contaminant mixture as was used by previous investigators.[5] Composition and particle size of the China clay are available upon request.

Mr. Harmon's discussion is well received. It is hoped that our interpretation is correct—that he endorses our approach to both a proposed industry standard change in rate of precipitation and water resistivity for wet tests, as well as using the proposed contamination test procedure as a nucleus for possible refinement into a general, industry standard type of test.

Clarifying the questionable points listed by Mr. Sakshaug is slightly complicated. For the results listed in Table V of the paper, we stated as one constraint that best results were obtained when the ratio of contaminant resistivity to thickness of coating was in the ratio of 410 to 640. Even though the results for samples 5A and 5B, with higher ratios, line up with results for the recommended ratios, the contaminant thickness of the two samples cited was so very thin that extreme difficulty was experienced in providing a coating of uniform thickness. For this reason, the higher ratios were excluded from the recommended range.

We observed the same tendency regarding the invariably higher flashover voltage of the first test point for each sample listed in Table V. At the moment, we can not explain this peculiarity. The meticulous care exercised during the investigation rules against the possible explanation offered by Mr. Sakshaug, because thorough and uniform wetting was one of the prime requisites before the test series was started. Similarly, we rule against the possible explanation offered by him for the results in Table VII. It is probably a case of semantics. We say "with the insulator partially dry" and the discusser says "variability in the wet condition." Nevertheless, we have stated in the paper, and repeat for emphasis, that further study is indicated concerning behavior during the drying period.

Regarding Mr. Carrara's and Mr. Zaffanella's discussion, we are anxiously awaiting a report from the Working Group on Measuring Technique of CIGRE Study Committee 8 on standardizing impulse wet tests. Their work may prove to be a valuable guide in the standardizing work by standards groups here in the U.S.A. The comments these two discussers have offered concerning the portion of the paper dealing with contamination are well received. The authors elected to use the ratio between the liquid contaminant resistivity and the dry deposit surface thickness as a measure of contaminant severity because it appeared to be more straightforward (because it involved only two quantities which required measurement in any case) and did not involve the introduction of a new quantity, namely, the equivalent salt deposit density.

The authors are indebted to the discussers for their welcome comments, and we appreciate their interest. It is hoped that the paper will spur other investigators in accumulating and disseminating related test data.

TRANSMISSION SYSTEM CONTAMINATION SYMPOSIUM

September 22 and 23, 1969
Holiday Inn, Lenox, Mass.

OBJECT: To allow interested General Electric Departments an opportunity to discuss common and individual problems with respect to increasing contamination consideration by our customers and standardizing bodies.

September 22, 1969

2:00 P.M.	Meet for coffee at the High Voltage Laboratory (Bldg. 9)
2:15 P.M.	Demonstration of flow-on method of contamination testing - HVL.
3:00 P.M.	Tour of outdoor research area of HVL.
3:45 P.M.	Tour of Project UHV facilities - Lenox.
5:30 P.M. - 6:30 P.M.	Informalities at the Holiday Inn.
6:30 P.M.	Dinner (Dutch Treat)

September 23, 1969 - Holiday Inn, Lenox, Mass.

8:30 A.M.	Welcome	A. Glassanos, Mgr. Engr. Power Transformer Dept.
8:45 A.M.	Test Methods and Standards for Contamination	G.W.Alexander - Mgr.HVL Power Transformer Dept.
	High Voltage Techniques for Testing	F.J.Turner - HVL
	Correlation of Test Methods with Natural Contamination	M. Kawai - Project UHV
	Standardization Activities in NEMA, IEEE, IEC, CIGRE	J.G.Anderson A.F.Rohlfs Dr. T.W.Liao
10:00 A.M.	Coffee Break	
10:15 A.M.	Design of Apparatus to Withstand Contamination	J.G.Anderson - Mgr. Project UHV - Electric Util. Engr. Opr.
	Lightning Arresters	E.C.Sakshaug
	Bushings	J.K.Easley
	Power Circuit Breakers	C.M.Ratliff
	Instrument Transformers	
	Power Line Carrier Current Equpt.	

September 23 (cont.)

11:15 - 12:00 Noon	Discussion Period	
12:00 - 1:00 P.M.	Lunch (Dutch Treat)	
1:30 P.M.	Design of Insulators to Withstand Contamination	Dr. T.W.Liao Mgr. - HVL-Lab. Oper. Transm. Div.
	Insulators	R.H.Lester Dr. R. Weller
	Gepol	F.C.Vose Dr. E.S.Wheeler A.E.Baker
	Comments on Designs	M.Kawai
	Statistical Approach Using Metifor and TNA	K.W.Priest
3:00 P.M.	Coke Break	
3:15 P.M.	Discussion of Common Problems and Company Technical Posture with Respect to Contamination	Dr. T.H.Lee Mgr. Laboratory Operation Transmission Div.
	Each participating Department to discuss their position on: Testing Methods Standards Specifications for Contamination	
	Summation	Dr. T. H. Lee
5:00 P.M.	Adjourn	

July 18, 1969

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High Voltage Laboratory
Pittsfield, Mass. & Philadelphia, Pa.
July 28, 1969

SUBJECT

Transmission System Contamination Symposium

Gentlemen:

In the last year there has been considerable activity among our customers and in standardizing bodies to specify contamination testing procedures for transmission line equipment. This activity had its basis in the work which has been done in CIGRE and IEC since contamination has been a more pressing problem in other areas of the world.

As we furnish equipment for systems, especially EHV and ultimately UHV transmission systems, we will be faced with the requirements of meeting contamination specifications. To this end the G.E. Liaison Committee to Project UHV suggested that a Company symposium on contamination would serve a very worthwhile objective. As a result of this, Dr. T. W. Liao and I were assigned the responsibility of organizing such a symposium. The agenda for this symposium is attached. It is organized to focus attention on:

1. Test methods and standardization activities dealing with contamination.

2. Design of apparatus to withstand contamination.

3. A discussion of common problems and our Company's technical posture with respect to contamination and possibly new standards.

You will notice under items 2 and 3 that we would very much like to have your participation in this program. Therefore, we would like to invite you to participate in this symposium and to nominate a spokesman for your department or operation. Please also note your inputs to the Company posture on this subject will have an important bearing on our activities in standardization work.

Very truly yours,

D W Alexander

G.W.Alexander - Manager
HIGH VOLTAGE LABORATORY - PITTSFIELD

T W Liao/sowa

Dr. T. W. Liao - Manager
HIGH VOLTAGE LABORATORY - PHILADELPHIA

/n
Att.

COMMENTS:

CONTAMINATION AND LINE DESIGN

K. W. Priest
October 1, 1969
Electric Utility Engineering
General Electric Company
Schenectady, New York

INTRODUCTION

With the acceptance of statistical techniques in line design, tower dimensions may no longer determined by switching surges or lightning. Figure 1 shows that additional insulator units, necessary for contamination performance may well impose the insulation design limits on EHV towers even in only lightly contaminated areas. Thus, improvement in insulator contamination performance will provide a reduced axial length of insulation. This will provide direct savings in tower heights and crossarm lengths.

Effect Of Local Weather On Contamination Performance

Utilizing the METIFOR weather model, the variation in insulation strength over time of contaminated insulators can be simulated using a contamination simulation program. This program will produce as output number of expected contamination flashovers over a 10 year period as a function of the number of insulator units.

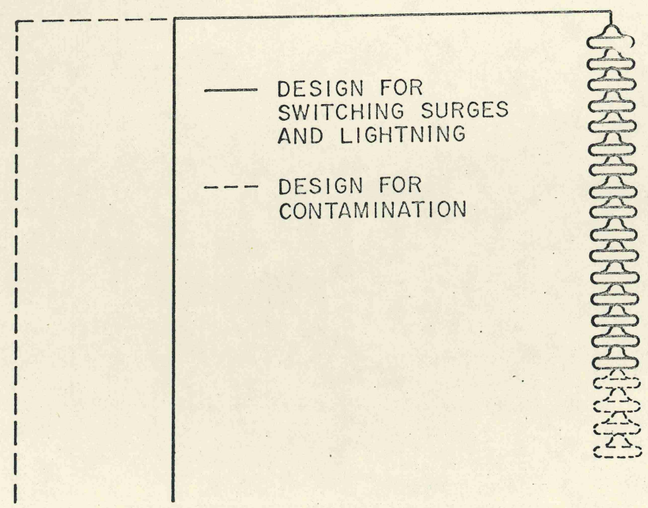


Figure 1

The basic input to this program is:

1. Hourly weather data.
2. Buildup of contamination as a function of time.
3. Washing effect of rain.
4. Insulation strength of the wet contaminated insulators as a function of the equivalent amount of NaCl deposit.

1. Weather Data. The hourly weather data used in METIFOR studies can be used for this study. The weather parameters of interest in contamination investigation are:

   Rain intensity and duration
   Fog intensity and duration
   Humidity
   Wind velocity
   Temperature
   Snow and freezing rain

2. Contamination Buildup. This information must come from measurements of the equivalent salt deposit densities on insulator strings allowed to remain in the field for specified times (without precipitation).

3. Washing Effect. Naturally contaminated insulators will be exposed to artificial rain of known intensity. The reduction in conductivity of the upper and lower surfaces of 5 selected insulator units in an insulator string will be recorded continuously. Knowing the relation between conductivity and the amount of contamination in mg NaCl per cm^2, the washing effect is determined.

4. Insulation Strength of Contaminated Insulators. Much of this work has been done and is continuing at Project UHV. However, local contaminated strings must be related to these tests.

Contamination Flashover Simulation

Based on the necessary information evaluated as described above, the amount of contaminants expressed in equivalent mg NaCl per cm^2 may be determined as a function of time. If fog occurs when the insulator is sufficiently contaminated (critical contamination) flashovers will occur (Figure 2). By using this program over several years of weather data, the frequency of contamination problems may be evaluated. In addition, since periodic washing may be simulated the ideal times to wash the units may be evaluated.

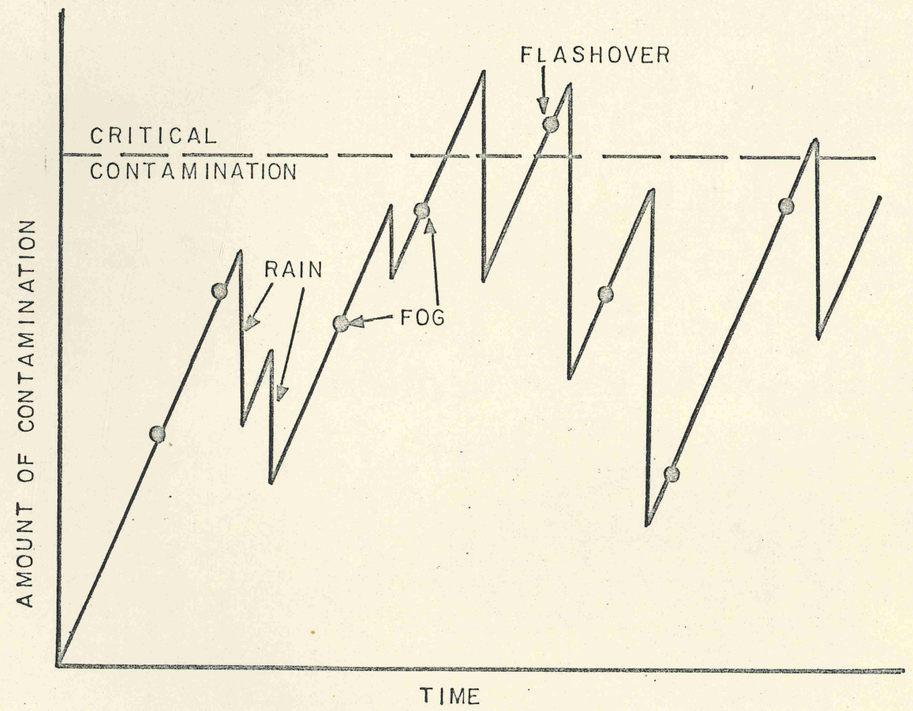


Figure 2

Results Of Contamination Study

The study program described here has the ability of incorporating in the calculation of contamination flashover rates all available knowledge concering the nature of contamination flashover and the specific contamination conditions in the area considered. The most uncertain input quantity will probably be the rate of buildup of contaminants. Figure 3 shows the type of format for the results of this study.

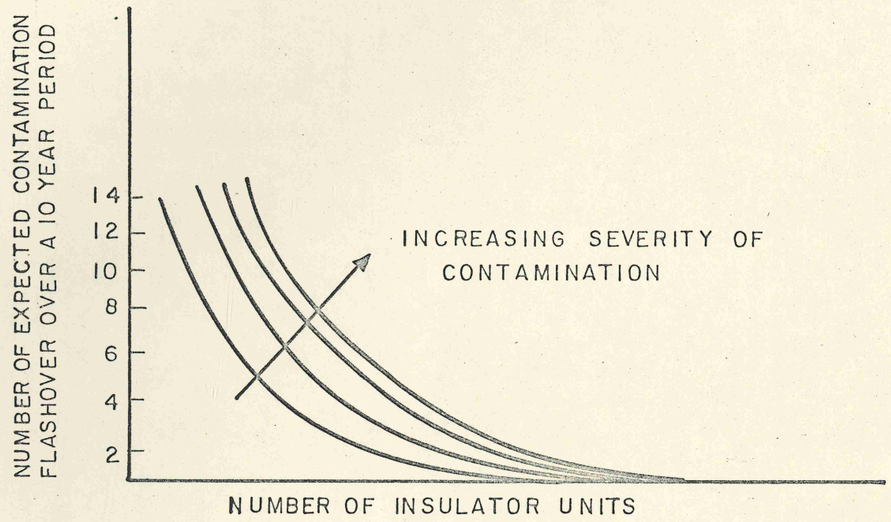


Figure 3

AL Libby

INSULATOR CONTAMINATION - PROBLEMS AND TESTS

F. J. Turner

I. INTRODUCTION

II. GENERAL PROBLEMS

- A. To Simulate or Not to Simulate Nature
- B. Measurements of Degree of Contamination
- C. Selection of Contamination Materials CONDUCTIVITY MATTERS MOST
- D. Method of Moisture Application - REPEATABILITY

III. POPULAR PRESENT DAY CONTAMINATION TEST METHODS

- A. Salt Fog Test - DEVELOPED IN ENGLAND
- B. Predeposit Test
  1. German method
  2. Dipping method
  3. Flow-coating
- C. ASEA Test Method
- D. Wet Contaminant Method

IV. SUMMARY

- A. Utility of Various Test Methods
- B. Correlation With Natural Conditions
- C. Need for Both Development & Practical Test Methods

SALT FOG METHOD

1. Insulators thoroughly cleaned.

2. Hung in suitable test chamber with a voltage source.

3. Voltage applied at a specified value - usually the insulator service value.

4. Salt fog introduced into chamber of a specified salinity measured in grams of salt per liter of water.

5. Voltage is held constant for one hour, and if no flashover occurs test is called a withstand.

6. Test is repeated at a higher or lower salinity depending on whether a withstand or flashover was obtained.

7. Insulators are evaluated on the basis of highest salinity fog withstood for one hour. Three withstands out of four tests at a given salinity are required to determine the maximum withstand.

8. Nozzle size, number of nozzles, distance to test insulators, rate of liquid flow are all controlled.

PREDEPOSIT METHOD

German Method

1. Insulators are thoroughly cleaned and dried.

2. Insulators are uniformly spray-coated with a mixture of Kieselguhr and salt in water.

3. The insulators are dried.

4. The dried insulators are placed in a fog chamber and service voltage applied.

5. Fog of approximately the same conductivity as the insulator would experience in service is then created in the room.

6. As the fog density increases the insulator leakage current will start to increase and will finally level off at the maximum conduction state.

7. Voltage is increased until failure occurs.

8. The increase in voltage above the service voltage is a measure of the margin the insulator has above its operating voltage for the contamination applied.

Remarks

Many variations of the German test have developed. Most investigators object to the flashover type of test method in that it does not give the insulators time to cook and form dry bands which can precipitate a flashover. Accordingly a withstand type of test is usually performed.

For applying the contaminant dipping is often preferred to spraying because of the difficulty in obtaining a uniform spray-coating. Recently flow-coating has been substituted for dipping in cases where size and geometry have made dipping impractical. Variables that have to be specified in order to obtain reproducible results are number, design and location of nozzles and circulation of fog in the tent. In the CESI laboratory they recently made similar tests in

which they pre-wetted the insulators completely in order to obtain a conductivity measurement. For the current development testing being performed at UHV, steam is generated to supply the fog for wetting the insulators rather than using air pressure to atomize a water stream.

ASEA TEST METHOD

1. Insulators are cleaned and dried.

2. Insulators hung in test chamber and test voltage is applied.

3. One kilogram of Kaolin dust is blown into the test chamber.

4. After 30 minutes the voltage is removed and 10 liters of water containing 0.5% NaCl are atomized and blown into the chamber during a 30 minute period.

5. Voltage is again applied to the insulators and a second 10 liters of water vapor containing 0.5% NaCl are blown into the chamber during a 30 minute period. Current pulses and flashovers are recorded.

6. If no flashover occurs the insulators are dried for about 3 hours and the cycle repeated without cleaning the insulators.

7. The number of test cycles until flashover occurs is a measure of the insulator performance.

WET CONTAMINANT METHOD

1. Thoroughly clean and dry the insulators.

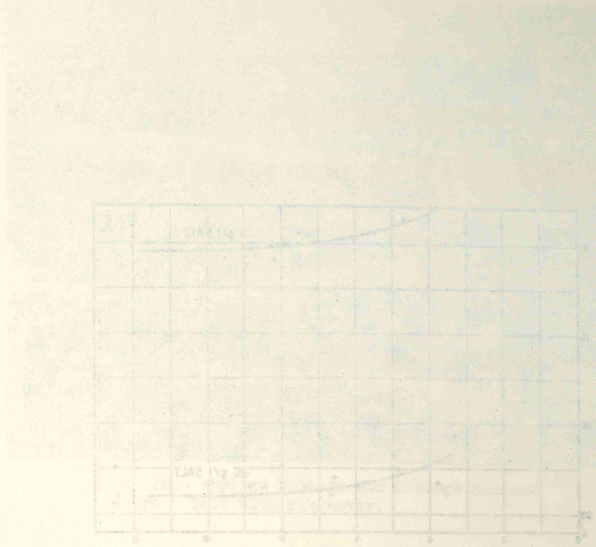
2. Flow-coat the insulators with a contaminating slurry. A preferred slurry contains 20 g/l of Cab-O-Sil HS-5, 1 g/l of Photo-Flo 600, and salt to obtain the desired conductivity.

3. Three to five minutes after the flow-coating is completed apply the specified voltage to the insulators and hold until all scintillation ceases or a flash-over occurs.

4. Repeat the above cycle twice. Three withstands are necessary at a given voltage level in order to certify that it is a withstand.

5. If a maximum withstand voltage is desired it is customary to raise the voltage steadily up to flashover on the first test and then drop down 10% from the flashover level for the second test. Subsequent tests are performed by changing the voltage in 5% steps depending on whether withstand or flashovers are obtained. Once again, three withstands are necessary in order to establish the withstand voltage level.

6. Levels of contamination can be specified by the salt concentration in the slurry, the conductivity of the slurry, the conductivity of the insulator string before test, or the salt deposit density on the insulator surface.



Transactions Paper

(Reviewed and Accepted for Publication)

DISCUSSION IN QUADRUPLICATE DUE February 14, 1969.

A NEW CONTAMINATION TEST METHOD

B. Macchiaroli
Inst.of Electrical Engineering
University of Naples
Naples, Italy.

F. J. Turner
Senior Member IEEE
General Electric Company
Pittsfield, Mass.

A paper recommended by the IEEE Transmission & Distribution Committee of the IEEE Power Group for presentation at the IEEE Winter Power Meeting, New York, N.Y., January 26-31, 1969. Manuscript submitted September 17, 1968; made available for printing October 23, 1968.

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Paper No.

69 TP 14 - PWR

A NEW CONTAMINATION TEST METHOD

B. Macchiaroli*
Institute of Electrical Engineering
University of Naples
Naples, Italy

F. J. Turner
High Voltage Laboratory
General Electric Company
Pittsfield, Massachusetts

ABSTRACT

A contamination test method is proposed that can be applied in any existing laboratory without adding expensive new facilities or equipment. The method can be applied to practically any piece of apparatus such as suspension insulators, bushings, lightning arresters, and station equipment.

In conjunction with the new test method a new contamination slurry is proposed. A large amount of data is presented concerning the physical and electrical properties of the proposed slurry and the reproducibility of the results.

INTRODUCTION

The artificial contamination methods now being employed by various laboratories around the world are all useful for development work, but they are generally designed for the investigation of certain natural conditions existing in specific areas. These methods generally require special and expensive test facilities and moreover it is often difficult to reproduce results among laboratories due to the many variables present, both in the method of making the test and in the composition of the contaminating slurries.

There is a need for a standard contamination test that can be performed readily in any laboratory with its existing facilities. The following prerequisites are suggested for such a test.

1. No special rooms or facilities should be required.
2. It must be capable of being applied to all apparatus.
3. The materials used in the contaminating slurry must be pure in the sense that they have the same physical and chemical characteristics at all locations.
4. The equipment used must be simple so that it can be duplicated readily.
5. The test method must have a minimum of arbitrary variables so that it is not dependent on the skill and experience of the operator.
6. The variability of the test results must be minimal.
7. The time required for the performance of the test and evaluation of the results should not be excessive.

With the preceeding factors in mind the authors have developed and thoroughly investigated the "wet contaminant" test method described in this paper.

THE WET CONTAMINANT METHOD

In selecting a contamination test method there are two general philosophies that can be followed:

1. The contamination can be put on selectively in a manner simulating natural conditions.
2. An attempt can be made to produce a uniform coat over the entire insulator surface.

Proponents of #1 argue that in the natural state contaminant is not as readily deposited on the protected surfaces of insulators of the fog type, and therefore any proposed test method should evaluate this protective quality.

Proponents of #2 argue that protected surfaces are only free of pollution during the early periods of exposure, and that insulators out in service for any reasonable period of time have as much or greater deposits of contaminant on the protected surfaces as they do on those exposed.

Undoubtedly both of the above arguments have merit and represent observations of people from different localities concerning conditions that exist in those particular areas.

It is the opinion of the authors that a standard test should take into consideration the most severe conditions, and therefore it was decided to use a variation of the uniform coating technique.

Two general methods have been used to obtain a uniform or semi-uniform coat. One method is to apply a fine spray to the insulating surface while the spray gun and insulators are moved relative to each other until in the operator's judgment a uniform coat has been produced. This method depends to a great extent upon the operator's judgment as to when he has a uniform coat, and also it is difficult to control the coating thickness. The second method consists simply of dipping the insulators in the contaminating liquid. By this method the coating can be reproduced quite readily, providing that the insulator surface has been prepared in a specified way before dipping. The main difficulty with this method is that it is almost impossible

*B. Macchiaroli was in the High Voltage Laboratory of General Electric Co., Pittsfield, Mass. on a NATO-CNR scholarship.

to dip large bushings, lightning arresters, and other large apparatus. It was therefore decided to use a variation of the dipping method that achieves identical results. That is, the insulators are flow-coated starting at the top and working to the bottom with a stream of liquid that coats the complete surface to the point of run-off. Previous to the flow-coating operation the insulators are prepared by washing in a neutral detergent, rinsing with tap water, and drying with compressed air. It has been found possible to design apparatus to flow-coat large structures and the resultant coating has been found to be quite reproducible. The quantity of the coating, however, in milligrams per square centimeter is somewhat less on the underside than on the top. This is also true of the dipping method and is probably due to the tendency to drip from the vertical surfaces. Furthermore, the flow-coating process can be carried on in any laboratory test area, and the residue flushed down the drain after test.

In the proposed "wet contaminant" test method the testing starts while the insulators are still wet, three to five minutes after the end of the flow-coating process. Although the objective of this test method is to determine the highest withstand voltage, initially a flashover is obtained to establish the voltage range. Therefore the voltage is brought up at a rate of about 7.5 kV/s to the flashover level, and the voltage recorded. A second test is then made repeating the whole washing, contaminating, and testing procedure except that this time an attempt is made to hold a withstand voltage ten percent below the flashover value. The complete test is repeated several more times until three withstands and no flashovers are received at some voltage level. This is then called the withstand voltage for the particular contamination level applied and is usually determined within five percent.

The above describes the method when used for development work to obtain design data. When used for a standard acceptance test method, one or more tests at the required withstand voltage can be specified.

There are two factors involved in this method that contribute to reproducible results. First, it has been found that with a little care the flow-coating nozzles can be shaped so that all of the insulator surfaces are covered to the point of run-off. The coating efficiency can be readily inspected by examination when wet, before applying the voltage, and also after the insulators have dried. Second, the flashover strength is dependent upon the amount of water held on the surface as well as the amount of solid material deposited. In the case of the "wet contaminant" method all tests are made with the surface completely wet.

The apparatus used to accomplish the flow-coating can be readily constructed from copper tubing. In Figure #1 is shown the apparatus used to coat suspension insulators. In this figure the contaminating liquid is pumped under pressure to the continuous copper ring which surrounds the insulators. On the inside surface of the ring 16 short sections of copper tubing about 6 mm in diameter (1/4") protrude. Half of these have a slight curve upward and sidewards so that the liquid is directed up along the grooves on the underside of the insulators. To illustrate the versatility of this method, Figure #2 shows one of the largest lightning arresters in the process of being flow-coated.

The degree of contamination on the insulator surface can be measured in several ways. First, the amount of salt and binder in the flow-coating liquid can be specified. Second, since the contamination coating is not altered by the test, all or part of an insulator coating may be washed off in distilled water, the conductivity measured, and the amount of salt in solution determined by comparison with standard curves. The equivalent salt deposit density can then be computed. Third, before applying high voltage to the test specimen a low voltage can be applied, and the leakage current measured. The conductance can then be computed, and finally the surface conductivity can be calculated by multiplying the conductance by the form factor for the surface being investigated.

The form factor is not generally available and must be calculated from measurements made on a drawing of the insulator cross section using the formula

$$f = \int_0^{\ell} \frac{d\ell}{\pi D(\ell)}$$

where ℓ denotes the total length of the leakage path and $D(\ell)$ the diameter of each element of the leakage path.

In the present investigation all of the above methods of measuring the surface pollution were used, but the authors believe that the best correlation with withstand strength can be obtained with surface conductivity.

In regard to the power source used for making contamination tests, other investigators have found, and it has been confirmed here, that there must be sufficient short circuit current available to prevent a voltage dip when flashover is imminent. It was found that with a small amount of pollution a source of five amperes was sufficient, but that as the contamination increased ten amperes or more were necessary.

THE CONTAMINATING MIXTURE

One of the objections to the clean fog method and other similar methods of test has been the variability of the constituents used in the contaminating slurry. Many types of

binders have been used such as Kaolin, Kieselgur and Aerosil. It was decided to try a pure form of SiO_2 which is readily available under the trade name Cab-O-Sil. This is a pyrogenic silica having an extremely small particle size. It is produced by the hydrolysis of silicon tetrachloride at 1100°C, and it is more than 99% pure. The basic chemical reaction is:

$$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$$

The large number of individual particles formed a group together in a chain like formation, and when dispersed in a liquid system, these "chains" join each other and form a "chicken wire" type of structure which entraps the liquid. This reduces the ability of the liquid to flow, and results in an increase of the viscosity.

After a great deal of experimenting with Cab-O-Sil it was found that the addition of a small amount of additive increased the viscosity and resulted in a gelatin like deposit that has the ability to hold liquid for a long peried of time. The manufacturers of Cab-O-Sil suggested several additives, but none were more effective for the present application or as easily obtainable as the wetting agent called Photo-Flo manufactured by the Eastman Kodak Company.

In order to determine the final contaminating mixture to be used throughout the investigation a large number of tests were performed. The aim of this part of the investigation was to determine the mixture that would remain in a stable wet condition for a long period of time.

These basic tests were performed on a string of five standard 5-3/4" by 10" (146 mm by 254 mm) Locke insulators having an outline as shown in Figure #3. The coatings were evaluated for the ability to hold moisture by applying a low voltage and measuring the leakage current versus time. Leakage current measurements were started in all cases three minutes after the flow-coating process was completed. The drying time can vary with the power dissipated; therefore in order to compare all coatings under the same conditions, the applied voltage was adjusted for each degree of contamination to maintain the power consumption below two watts.

For each mixture investigated five tests were made. After each test, the density of the salt deposit was determined on the top insulator of the string, the bottom insulator of the string, one additional insulator flow-coated but not tested, and finally one insulator that was coated by dipping in the same slurry. Measurements of the density of the salt deposit were made not only for the whole insulating surface, but also for the top and bottom surfaces separately. The top surface was defined for this purpose as that area wetted by a vertical rain when the insulator is hanging vertical.

The results of these basic tests to evaluate the various mixtures are presented in Figures #4 through #8 and Table I.

The surface conductivity of the insulators was used as a measure of the ability of the contaminant to hold water over a period of time. The average value of this quantity is plotted versus time after flow-coating in Figures #4 and #5 for a binder containing 2.5 grams per liter of Cab-O-Sil and 25 grams per liter of Cab-O-Sil respectively with various concentrations of salt from 2 to 100 grams per liter in each case. In addition, tests were made with 50 grams per liter of Cab-O-Sil, but it was found that the viscosity of the slurry was not stable for such a large concentration.

In Figure #6 the results obtained with 20 grams per liter of Cab-O-Sil and an additive of 1 gram per liter of Photo-Flo 600 are shown. This amount of Photo-Flo additive was found to be sufficient by making several preliminary tests.

At the left of each of the curves in Figures #4 through #6 are shown two numbers separated by a diagonal. These represent the initial variability of the results obtained for the five tests and the variability after 10 minutes. Thus, for 50 grams per liter in Figure #4, there was an initial dispersion in the conductivity measurements of ± 10% and this grew to ± 35% after 10 minutes.

In Table I the percent conductivity changes with respect to the initial, for times after flow-coating of 10 minutes and 15 minutes, have been tabulated for the various mixtures. From these tests the following conclusions may be drawn:

1. With salt alone for a contaminant the initial surface conductivity is low, has a wide variation, and the surface dries rapidly.

2. For a given amount of salt the initial surface conductivity increases with the amount of Cab-O-Sil. Although 25 grams per liter of Cab-O-Sil results in a fairly constant conductivity for the first 10 minutes when above 25 grams per liter of salt are used, the change is very large for low salt concentrations. Using 50 grams per liter of Cab-O-Sil gave better results, but it was found difficult to maintain a constant viscosity mixture, and this resulted in a large dispersion in the surface conductivity.

3. By far the most stable results were obtained when 1 gram per liter of Photo-Flo 600 was added to a slurry containing 20 grams per liter of Cab-O-Sil. Figure #6 summarizes the data for this mixture, and it can be seen that the maximum variation in the initial conductivity was only 2%, and the decrease over 30 minutes was very small. Table I shows that the maximum change in conductivity over a 10 minute period was only 4% and after 15 minutes 6%. Thus, with this binder, for a given salt concentration there will be negligible variation in the initial conductivity of the insulators, the degree of wetness of each insulator will be the same, and it is not necessary to closely control the time at which the voltage is applied after the flow-coating has been completed.

4. The amount of salt on the upper surface, lower surface, and the average for the complete insulator are shown in Figure #7. From this figure it can be seen that the density of the salt deposit is linear with the salt in the slurry. It also increases with the amount of Cab-O-Sil and is the highest when the Photo-Flo additive is used. For all cases, the salt density on the upper surface is greater than that for the lower surface. This is also true for the dipping method of contamination and does not affect the overall value of the test method.

5. The dispersion of the density of the salt deposit on the insulator surfaces from test to test was found to be generally less than 15 percent although it occasionally reached as high as 20 percent.

6. No difference in the amount of salt deposit was found between the dipping and flow-coating methods.

7. The use of the Photo-Flo additive results in an increase in both the salt deposit density and the surface conductivity; therefore, less salt is required in the slurry to achieve a given degree of contamination.

8. In Figure #8 a plot is shown on log-log paper of surface conductivity versus grams per liter of salt for three levels of Cab-O-Sil binder. When plotted on this type of paper, a linear relation was found for all three cases.

EFFECT OF TEMPERATURE AND HUMIDITY

All of the tests up to this time were performed with both the mixture and ambient temperature in the range of 22°C to 25°C. Since conductivity often is a function of temperature, it was decided to determine the effects of relatively large differentials in temperature between ambient and mixture. Accordingly, additional conductivity measurements were made for several mixtures on insulator strings with the ambient temperature in the range of 22°C to 25°C and a mixture temperature of 12°C to 13°C. Also, the ambient temperature was lowered to 7°C to 8°C and tests made with mixture temperatures around 22°C. For all of these tests the results have been within the spread that could be expected from test to test with different slurries; therefore, it can be concluded that the temperature of the ambient and mixture within a reasonable range has no appreciable effect on the surface conductivity.

Similarly, the ambient humidity has been varied from 15 percent to 70 percent with no noticeable effect on the data.

TESTS ON INSULATOR STRINGS

As a result of the information gathered in the investigation of the contamination coating, it was decided to make all further withstand and flashover tests with a contamination slurry containing 20 grams per liter of Cab-O-Sil, 1 gram per liter of Photo-Flo 600, and various levels of salt to achieve the contamination level desired.

Withstand and flashover tests were performed on suspension insulator strings composed of two types of insulators:

(1) 9 standard Locke units, Cat. 1840K
(2) 8 fog-type Locke units, Cat. 18134.

The main characteristics of these insulators are tabulated in Table II and shown in Figure #3.

The tests were carried out for salt concentrations from 2 grams per liter to 20 grams per liter in the manner already described, and for each test measurements were made of both the salt deposit density and initial surface conductivity. These quantities are shown in Figures #9 and #10, and the withstand voltages are shown in Figures #11, #12 and #13. In Figures #11 through #13 it is seen that the relative withstand values of the two insulator strings are the same whether plotted against grams per liter of salt in the slurry, density of deposit on the surface, or conductivity of the surface. In each case a curve is obtained which is apparently leveling off as large concentrations of salt are reached. In each case the fog-type insulator is somewhat superior to the standard insulator, a situation that was somewhat expected based on the longer creepage path. The difference in strength is most apparent when plotted against the grams of salt per liter of solution. This is caused by a higher average salt deposit per square centimeter on the standard type unit which results in a higher conductivity. These differences in average salt deposit density and surface conductivity are due to the larger lower area of the fog-type units where the salt density is less, as already mentioned. When plotted against salt deposit density or surface conductivity, however, the effect of the larger area of the underneath portions of the fog-type units is eliminated, and the insulators are compared in a more realistic fashion on the merits of the contour design. It can also be argued that surface conductivity is a more basic quality, and therefore a more suitable basis for comparison. On the other hand, it is the most difficult of the measurements to make or predict, and therefore may be less desirable from a practical standpoint.

As a matter of interest, oscillograms of the leakage current and line voltage are shown in Figures #14 through #16. Figure #14 shows on a relatively fast sweep the distortion that occurs in the current wave due to the streamers that occur during a withstand run very near the flashover

level. Note that the voltage source is so stiff that it is relatively unaffected. Figure #15 gives a record of the overall activity that occurs during a withstand run, and Figure #16 shows a flashover. In Figure #17 is shown the scintillation that occurs on the insulators during a withstand run that is very close to the flashover voltage.

TEST REPRODUCIBILITY - THEORETICAL APPROACH

In order to come to some conclusions as to the reproducibility of the results obtained with the proposed test method, an attempt has been made to analyze the variability in the withstand voltage that can result from the parameters involved. These are:

1. salt deposit density on the insulator surfaces,
2. wetting degree at the moment of test,
3. layer thickness,
4. layer temperature,
5. rate of voltage increase.

Another important variable is the short circuit current of the power supply concerning which it has already been stated that it must be large enough to hold the voltage constant during periods of heavy scintillation. When this condition is complied with, there is no appreciable influence on the results.

Considering the first four parameters, it is noted that they can be lumped together under surface conductivity. Therefore, we can consider that the withstand voltage V_w is a function of:

$$V_w = f\left(c, \frac{dV}{dt}\right) \qquad (1)$$

where c is the surface conductivity and $\frac{dV}{dt}$ the rate at which the voltage is increased to the withstand level. Accordingly, changes or variations in the withstand voltage can be expressed as:

$$dV_w = \frac{\partial V_w}{\partial c}\, dc + \frac{\partial V_w}{\partial\left(\frac{dV}{dt}\right)} \frac{dV}{dt} + \Delta \qquad (2)$$

Here the quantity Δ has been added to account for the dispersion in results that could be obtained due to the statistical variation of unknown factors in the breakdown process even if all other quantities were held constant.

The term $\frac{\partial V_w}{\partial c}$ is the slope of the tangent to the curve of withstand voltage versus surface conductivity. This value changes with the surface conductivity. Representative values are as follows:

		μS		
		15	30	60
$\frac{\partial V_w}{\partial c}$	Std.	2.2	0.83	0.31
	Fog	1.9	0.86	0.31

The term, dc, can be considered as the variability that can exist in the surface conductivity from test to test for the same slurry. In Figure #6 it is seen that when working with the same slurry a variability of 2% has been found. However, when different slurries are mixed up it is estimated that an error of 2% is possible in each measurement. Since there are four components in the slurry, the estimated error in preparing a slurry could reach 8%. Therefore, for tests made at different times with different mixtures the total conductivity variability from this cause could reach 10%.

In order to obtain an approximation for the term $\frac{\partial V_w}{\partial\left(\frac{dV}{dt}\right)}$ a large number of tests are necessary with the same slurry so that the change due to surface conductivity is minimal. This is quite difficult due to the time involved and the quantity of the same mixture required; therefore, it was decided to work with the flashover voltage, V_f, instead and use the results as a reasonable approximation for those that would have been obtained for V_w.

Tests were carried out on standard insulators for two different salt concentrations, and the results are shown in Figure #18. The two curves obtained are in fairly good agreement and the following observations can be made:

a. The $\frac{\partial V_f}{\partial\left(\frac{dV}{dt}\right)}$ as determined by the slopes of the curves in Figure #18 decreases when going from 3 kV per second to 12 kV per second for both curves with some average values as follows:

Rate of Rise	$\frac{\partial V_f}{\partial\left(\frac{dV}{dt}\right)}$
5 kV/s	- 1.2
7.5 kV/s	- 0.4
10 kV/s	- 0.07

b. Because of the variability of the data in Figure #18, a band should be considered rather than a single line through it. This can be accounted for to some degree by variations in surface conductivity, but is is probably more likely due to the unknown factors combined under Δ in equation (2). In any event, the dispersion of results is greatest for slow rates or rise, being about ± 5% at 3 to 4 kV per second and ± 3% at 7 to 8 kV per second.

c. When working in this voltage range it is difficult to control the voltage for rates of rise greater than 10 kV per second.

Based on the above observations, a voltage rate-of-rise of 7.5 kV per second was selected as standard for this voltage range. If we assume that we can maintain a speed of 7.5 kV per second within ± 15%, then the term

$$\frac{\partial V_f}{\partial\left(\frac{dV}{dt}\right)}\left(\frac{dV}{dt}\right) \text{ becomes } (-0.4)(\pm 15\%) = \pm 6\%$$

Adding up all of the terms for equation (2), for a conductivity of 53 microsiemens which corresponds to a salt content of 10 grams per liter for standard insulators, we have the following:

$$dV_w = (0.35)(10) + (.4)(15) + 3 \approx 12\%$$

In a similar manner the expected variability for V_w can be calculated for other conductivity values to yield the following table:

Salt in Mixture g/ℓ	dV_w Std. Ins.	dV_w Fog Ins.
5	19%	23%
10	12%	14%
20	9%	9%

This variability is what could be expected when different mixtures used for several withstand tests and the withstand values are plotted versus salt in the slurry or on the surface.

On the other hand during the present investigation, when only one slurry was used for one complete test series, only a 2% variation in the initial conductivity was found. In this case the 8% error possible due to using different mixes has been eliminated and the expected variability in the withstand values becomes:

Surface Conductivity (μS)	dV_w Std. Ins.	dV_w Fog Ins.
15	13%	13%
30	11%	11%
60	10%	10%

TEST REPRODUCIBILITY - EXPERIMENTAL

In order to verify that the withstand voltages for tests conducted at different times would fall within the theoretically calculated range, the withstand tests were repeated after a time interval of two months. In this second series of tests, both a different test area and a different operator were used.

The results of this second series of tests are plotted in Figures #11 through #13 and a comparison with the original values is tabulated in Table III. From Table III it is seen that the results are in surprisingly good agreement with the initial tests, and the percent change is well within the calculated limits for each salt concentration.

The reproducibility of results found here is much better than usual for contamination testing, and at the present time it is not known whether it is due to the test method, the slurry composition, or a combination of both. It would be interesting to investigate the reproducibility of results with the same test method but different binders in the slurry.

CONCLUSIONS

1. A new contamination test method has been proposed that can readily be applied to all types of insulating structures, and does not require highly specialized equipment or test facilities.

2. The proposed test method is not intended to reproduce any particular natural conditions, but with experience correlation could come naturally as data are accumulated in service for insulating structures that have been tested by the new method.

3. A new contaminating slurry has been developed which is composed of well defined materials and has the ability to hold its original wet condition over an appreciable time. The salt deposit density and the surface conductivity of insulators contaminated with this slurry are independent of both ambient temperature and humidity and also that of the slurry temperature.

4. It is the authors' opinion that the surface conductivity of the insulators should be used as a measure of the degree of contamination.

5. Although further work is required, it appears that the reproducibility of results with the new method is good enough so that it can be considered for a standard contamination test. It would be desirable for some other laboratory to perform a series of withstand tests in order to check the results obtained and determine if any problems exist in this respect.

Table I. Percentage Conductivity Change with Respect to Initial Value

Binder		After 10 Minutes				After 15 Minutes			
Cab-O-Sil g/l	Photo-Flo g/l	Salt g/l 2	25	50	100	Salt g/l 2	25	50	100
2.5	0	88	75	55	38	98	100	100	70
25	0	53	9	9	11	88	14	20	24
50	0	9							
20	1	4	3	1	2	6	4	3	5

Table II. Main Characteristics of Tested Strings

Insulator Type	Number of Units	Overall Length mm	Leakage Path mm
Standard Disk	9	1314	2630
Fog Disk	8	1320	3450

Table III. Comparison of Two Test Cycles for Various Salt Concentrations

		Insulators						
		Standard				Fog		
Salt in Mixture	(g/l)	2	5	10	20	5	10	20
Withstand Voltage First Test	(kV)	115	77	61	53.5	97	76	63
Withstand Voltage Repeated Tests	(kV)	125	80	58	51	94	71	60.5
Percentage Change of repeated test with respect to the first	(%)	+9	+4	-5	-5	-3	-7	-4

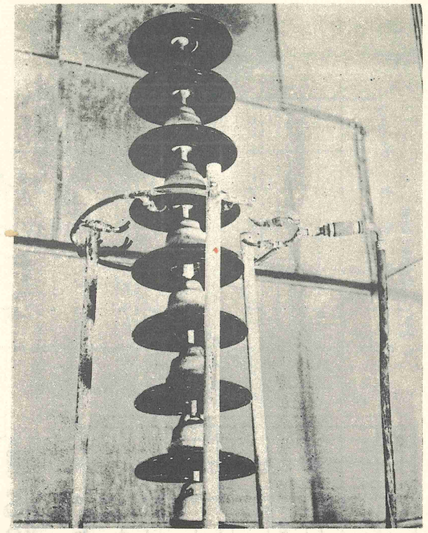

Fig. 1. Apparatus for Flow-coating Suspension Insulators.

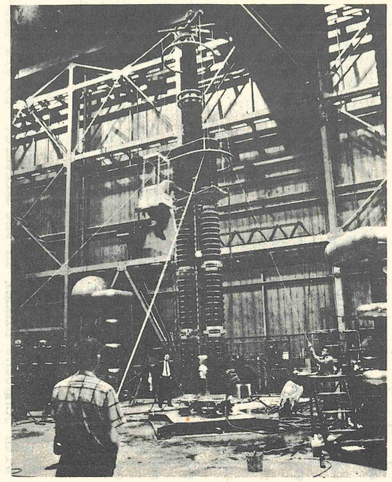

Fig. 2. Flow-coating Method Being Applied to a Lightning Arrester.

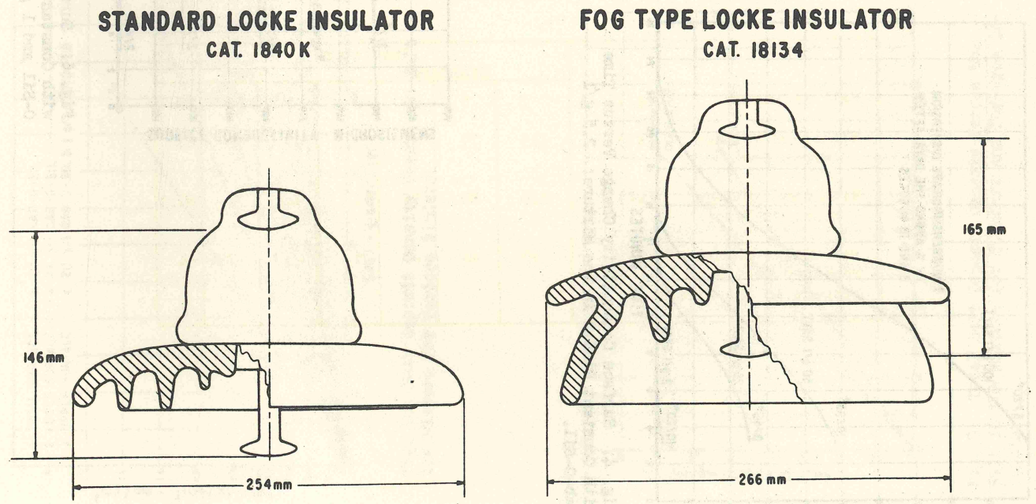

Fig. 3. Test Insulators.

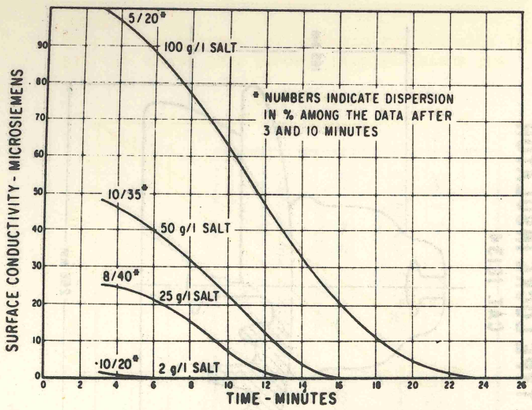

Fig. 4. Surface Conductivity Change Versus Time with Constant Binder in the Mixture: 2.5 g/l Cab-O-Sil.

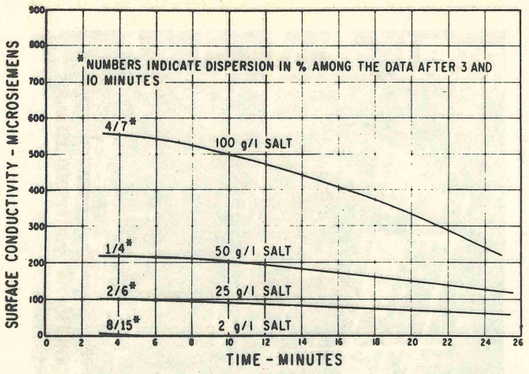

Fig. 5. Surface Conductivity Change Versus Time with Constant Binder in the Mixture: 25 g/l Cab-O-Sil.

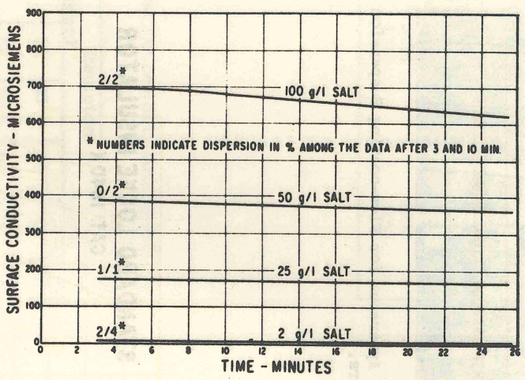

Fig. 6. Surface Conductivity Change Versus Time with Constant Binder in the Mixture: 20 g/l Cab-O-Sil and 1 g/l Photo-Flo.

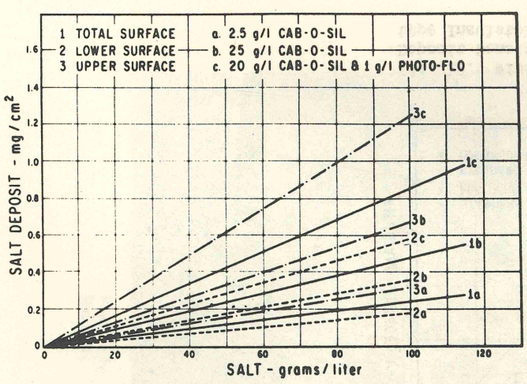

Fig. 7. Salt Deposit Density Versus the Salt in the Mixture for Various Binders.

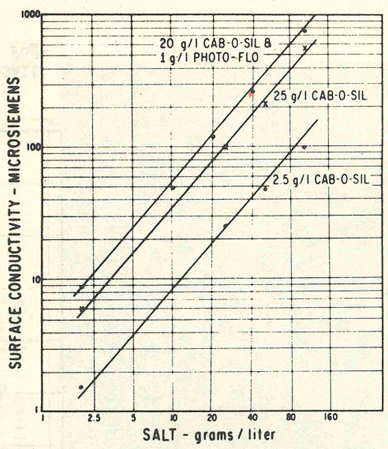

Fig. 8. Surface Conductivity Versus the Salt in the Mixture for Various Binders.

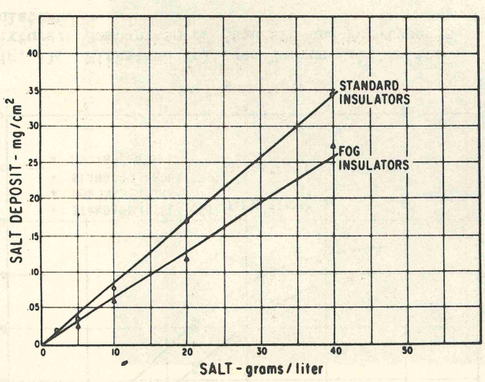

Fig. 9. Total Salt Deposit Density Versus the Salt in the Mixture for Standard and Fog-type Insulators.

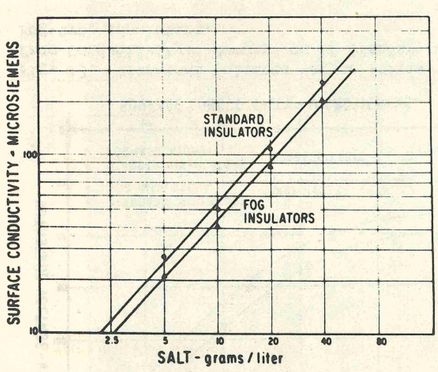

Fig. 10. Initial Surface Conductivity Versus the Salt in the Mixture for Standard and Fog-type Insulators.

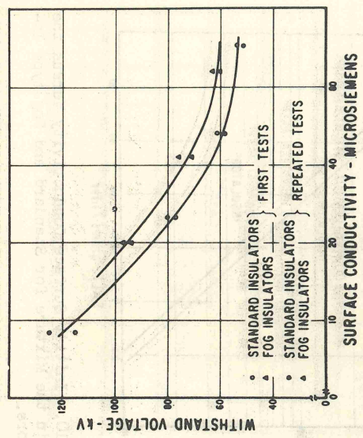

Fig. 13. Withstand Voltages Versus Initial Surface Conductivity: Comparison of Standard and Fog-type Insulators.

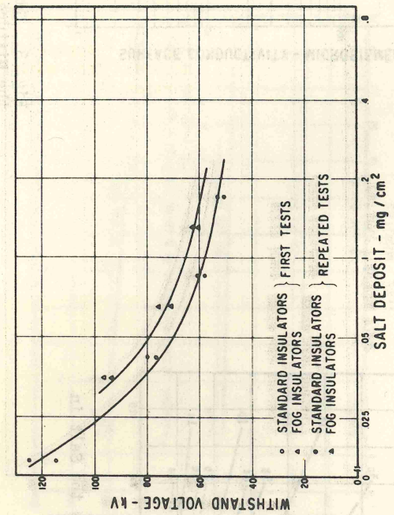

Fig. 12. Withstand Voltages Versus Average Salt Deposit Density: Comparison of Standard and Fog-type Insulators.

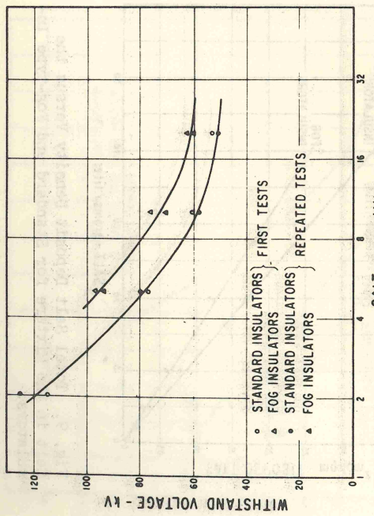

Fig. 11. Withstand Voltages Versus Salt in the Mixture: Comparison of Standard and Fog-type Insulators.

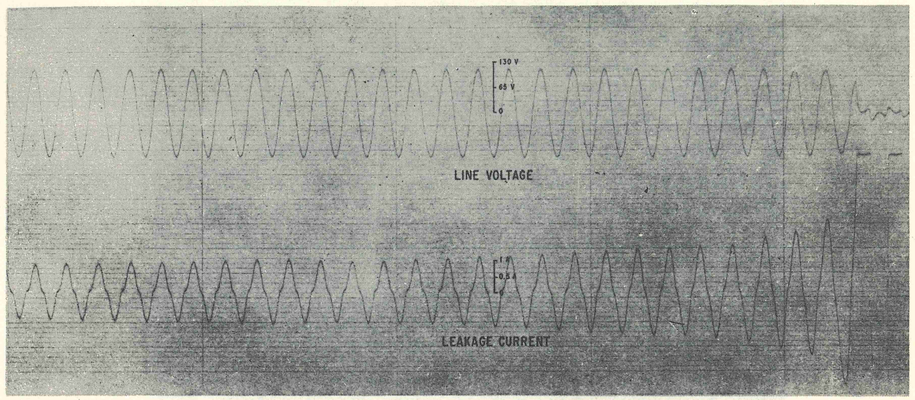

Fig. 14. Applied Voltage and Leakage Current Record: Test with Flashover Showing Wave Distortion.

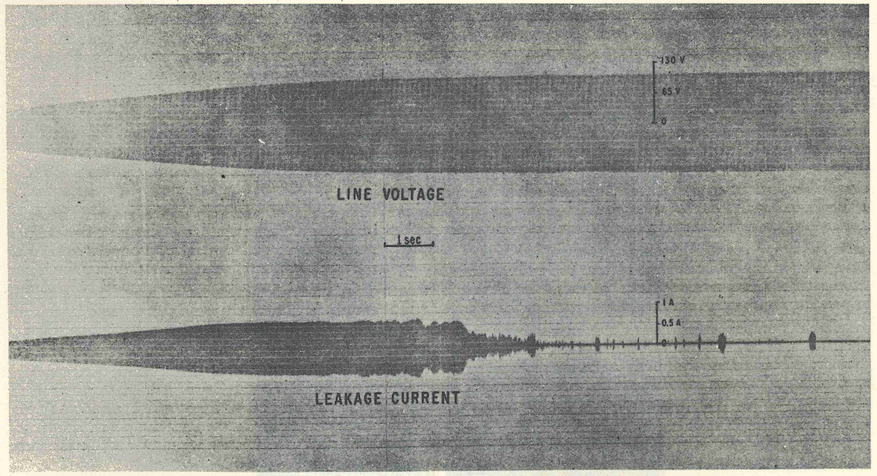

Fig. 15. Applied Voltage and Leakage Current Record: Test with Withstand.

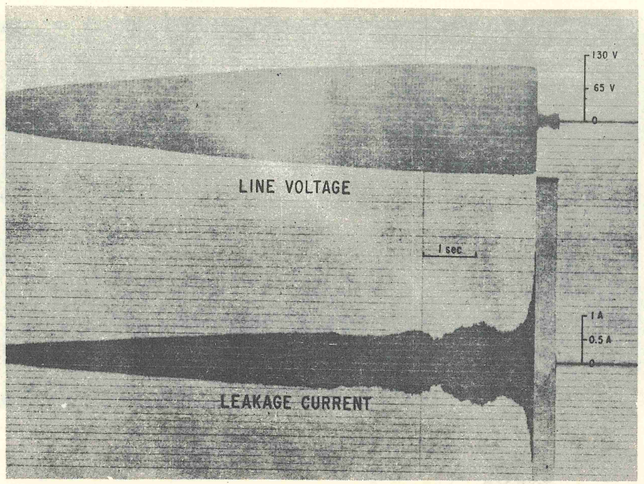

Fig. 16. Applied Voltage and Leakage Current Record: Test with Flashover.

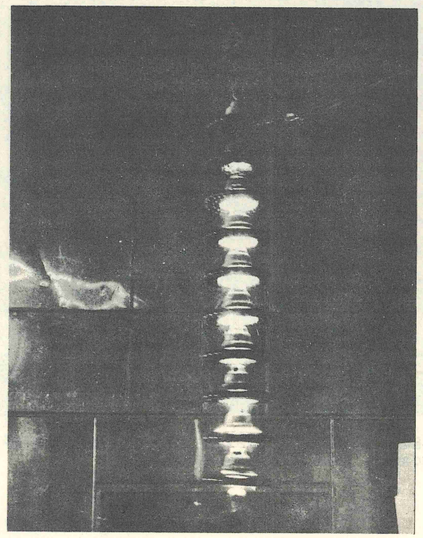

Fig. 17. Scintillation on Standard Insulator String During a Withstand Test.

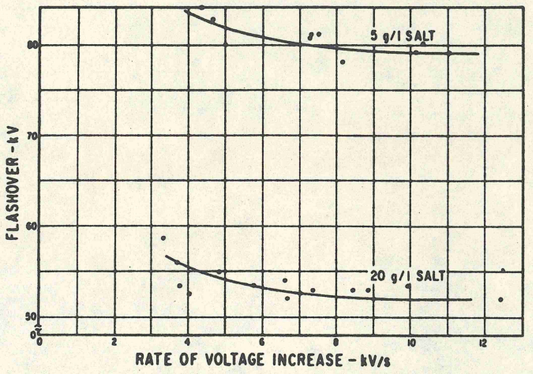

Fig. 18. Flashover Voltage Versus Rate of Voltage Increase for Slurries with Two Different Salt Concentrations.

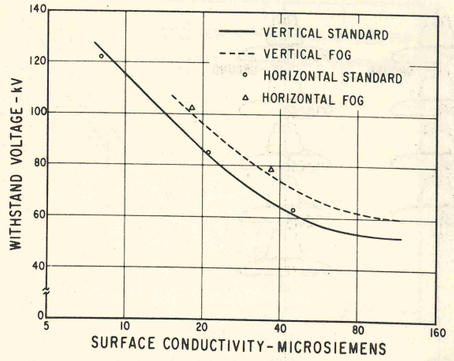

Fig. 12. Vertical and Horizontal Strings. Withstand Voltages Versus Surface Conductivity.

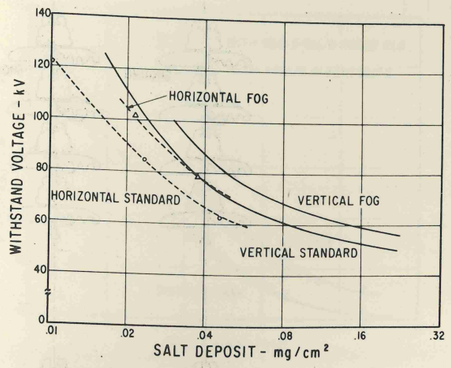

Fig. 13. Vertical and Horizontal Strings. Withstand Voltages Versus Total Salt Deposit Density.

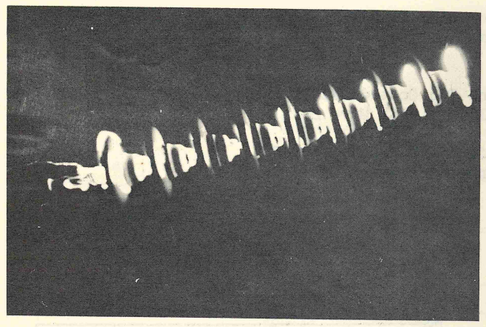

Fig. 14. Horizontal Standard Unit String During a Withstand Test.

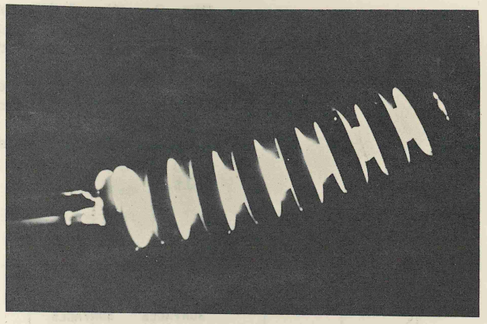

Fig. 16. Horizontal Fog Unit String During a Withstand Test.

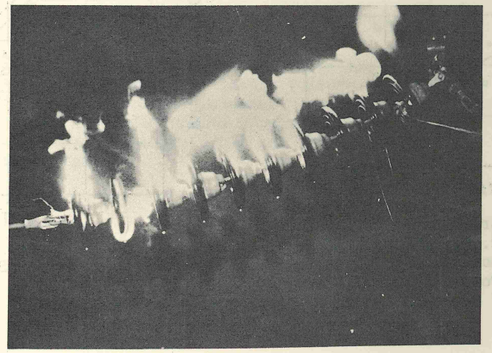

Fig. 15. Horizontal Standard Unit String During a Flashover Test.

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A STUDY OF SOME VARIABLES AFFECTING CONTAMINATION TESTING USING THE WET CONTAMINANT METHOD

B. Macchiaroli
Institute of Electrical Engineering
University of Naples
Naples, Italy.

F. J. Turner
Senior Member IEEE
General Electric Company
Pittsfield, Mass.

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A STUDY OF SOME VARIABLES AFFECTING CONTAMINATION TESTING USING THE WET CONTAMINANT METHOD

B. Macchiaroli*
Institute of Electrical Engineering
University of Naples
Naples, Italy

F. J. Turner
High Voltage Laboratory
General Electric Company
Pittsfield, Massachusetts

ABSTRACT

The test results reported in reference (1) for which Cab-O-Sil was used as a slurry binder are compared with tests made using a slurry having a binder of Kaolin and Bentonite.

Also investigated were the effect of non-uniformity of the contaminating coating, and the strength of horizontal versus vertical contaminated insulator strings.

INTRODUCTION

In reference (1), "A New Contamination Test Method", a wet contaminant method was proposed and applied to insulator strings. This method is very simple and capable of being applied to all apparatus without requiring special rooms or facilities. The contaminating slurry was a mixture of:

20 g/l	Cab-O-Sil**
1 g/l	Photo-Flo 600**
2 to 20 g/l	NaCl

For each test the insulators are washed in a neutral detergent, rinsed with tap water, dried with compressed air, and then flow-coated with multiple streams of the prepared slurry. Five minutes after the end of flow-coating, while the insulators are still wet, voltage is applied and increased with a constant rate of about 7.5 kV/s. In the first test, the voltage is increased until flashover, whereas in subsequent tests an attempt is made to hold a withstand voltage below the preceding flashover level. The test is repeated several times until the highest level is determined at which three withstands can be obtained and no flashovers occur. This is called the withstand voltage for the particular contamination level and is determined within five percent.

Many tests were performed with this procedure on different insulator types, and the results were also compared with those obtained on the same insulators with the clean fog method and with others in different laboratories in natural and artificial tests[2]. The repeatability of the tests in the same laboratory and the agreement with test results of other investigators were very good.

In order to have more information about variables that might affect this proposed contamination test method, it was decided to carry out further research work, and particularly:

a. to test with a different slurry to check the influence of the mixture on the test results and on the test reproducibility,

b. to analyze the influence of non-uniform distributions of the contaminant,

c. to compare horizontal and vertical strings of insulators.

Only standard and fog disk insulators were used for the investigations. The main characteristics of the tested strings are shown in Figure #1 and Table I.

TESTS WITH KAOLIN AND BENTONITE

Many other investigators, with different test methods, are using Kaolin alone or mixed with Bentonite[3,4,5,6], and for this reason it was decided to investigate the wet contaminant method with these components replacing Cab-O-Sil as a binder.

However, before applying the wet contaminant procedure, it was necessary to make a preliminary investigation to determine the proportions for a slurry so that the salt deposit density, the initial surface conductivity and the wetting degree would be as constant as in the slurry using Cab-O-Sil and Photo-Flo. The characteristics of the slurry are indeed a very important element to insure good reproducibility in the test results.

This investigation was conducted in the same manner as that which concluded with the choice of Cab-O-Sil and Photo-Flo[1], and it was found that the amount of salt, Kaolin and Bentonite have an influence on salt deposit density and on surface conductivity of contaminated strings similar to that found when using Cab-O-Sil and Photo-Flo.

A large inconsistency was found, however, when bags of Kaolin and Bentonite from different lots were used. Changing the lots but keeping the same proportions of the slurry components, the salt deposit density and the surface conductivity changed considerably. An example of this inconsistency is shown in Figure #2, where the surface conductivity for two different lots

* B. Macchiaroli was in the High Voltage Laboratory of General Electric Co., Pittsfield, Mass. on a NATO-CNR scholarship.

** Trade name.

of Kaolin and Bentonite is plotted versus time for a slurry containing 5 g/l of salt. The capital letter "A" indicates curves for slurries containing Kaolin and Bentonite from the first lot, and the capital letter "B" indicates the curves obtained with the lots obtained many months later.

When Bentonite A was used with Kaolin B, an initial conductivity 250% higher was found than when Bentonite A was used with Kaolin A. Also, a definite difference in the drying time was found. Similarly, when Kaolin B was used with Bentonites A and B, a difference of 45% was found in the initial conductivity value, and there was again an appreciable difference in the drying time.

The information in Figure #2 is very important because the high voltage test results are greatly influenced by the surface conductivity, and therefore it would be impossible to obtain reproducible data with bags of Kaolin and Bentonite selected at random.

This difference in behavior among batches of Kaolin and Bentonite had been expected because both Kaolin and Bentonite are not pure materials. Some factors which may control the behavior of Kaolin include mineral and chemical composition, the nature and quantity of minor compounds, crystalline structure and particle construction (7). These clays contain varying amounts of minor impurities among which are iron, titanium, alkaline earths, alkalies and sulphur compounds that, if present in appreciable amounts, can effect such properties as viscosity which in this kind of test is an important factor. A chemical analysis was not performed to find the proportions of the several components of the Kaolin and Bentonite used because this was not the purpose, but in Table II some data reproduced from references (8) and (10) are reported to illustrate the differences that can exist.

Bentonite, also, has a variable composition and small changes can give radically different results. The addition of a small amount of magnesium oxide, for instance, increases the property of forming a gel (9).

Therefore, the subsequent tests were performed using only one type of Kaolin and Bentonite, namely Kaolin B and Bentonite A, and the final adopted proportions for the contaminating slurry were:

40 g/l	Kaolin
20 g/l	Bentonite
1 to 10 g/l	NaCl

In Figures #3 and #4, the average total salt deposit density and the initial surface conductivity versus the salt added in the slurry are reported for both the standard and fog insulators.

In all the tests performed, including those with high voltage, the change in the initial surface conductivity was less than 4%. The wetting degree versus time was checked in three tests with each salt concentration, and it was found that the maximum change of the surface conductivity in comparison with the initial value was 3% after 10 minutes and 5% after 15 minutes.

When high voltage was applied to the strings coated with slurries containing Kaolin and Bentonite, it was noted that the activity near the insulator pins lasts for a longer period of time than when coated with Cab-O-Sil and Photo-Flo. Moreover, when a flashover occurs during an attempt to hold voltage, this happens generally in the first half-minute with Cab-O-Sil and Photo-Flo, but it may be after more than one minute with Kaolin and Bentonite.

The withstand voltages obtained with Kaolin and Bentonite are compared to those obtained previously with Cab-O-Sil and Photo-Flo in Figures #5, #6 and #7 where they are plotted versus surface conductivity, salt deposit density, and salt in the slurry. The data from two separate series of tests are plotted for each type of binder, thus an idea of test reproducibility can also be gained from these figures.

When surface conductivity is considered and data corresponding to both types of slurries are compared (Figure #5), it can be noted that the results with the standard disks are almost identical, with only a difference of about 5% at 10 μS. For the fog units, however, there is a difference of about 5% throughout the whole range of surface conductivity.

From these tests one of the statements made in reference (2) is confirmed; namely that the withstand value for a contaminated insulator string is roughly the same for a given conductivity and is independent of the test method and contaminant. Also, when the band of data defined by the single points of Figure #5 are considered instead of the average curves, it can be seen that the change in the withstand voltage is within the theoretical limits calculated for the wet contaminant method (1).

In Figure #6 the data are plotted with the salt deposit density as a parameter, and the results obtained with both types of slurry are in very good agreement. Since the withstand voltage is a function of both salt deposit density and degree of wetness, these results indicate that the slurries were about equal in their ability to hold water on the surface. This was a fortunate coincidence in this case, as of course it would not necessarily be true of all slurries.

Finally, withstand voltages versus salt in the slurry are considered in Figure #7.

It is noted that the test results with 10 g/l of salt are about the same. If this happens with one amount of salt, it might be expected to be true for all salt concentrations, but this did not turn out to be the case. The

withstand voltages obtained with Kaolin and Bentonite when the salt in the slurry is decreased are lower than those obtained with Cab-O-Sil and Photo-Flo. With the fog units, the difference between the highest withstand voltage obtained with Cab-O-Sil and the lowest with Kaolin and Bentonite at 5 g/l of salt is almost 13%, and with the standard disk at 2 g/l it is 17%.

The reason for this can be found in the fact that Kaolin and Bentonite are not pure materials and, when the salt in the slurry is decreased, the percentage influence of the conductive products is larger resulting in lower withstand voltages than those obtained with the same salt in the slurry using a pure material as a binder. It was found that a slurry with 40 g/l of Kaolin and 20 g/l of Bentonite and no salt added in the water had a resistivity of 3600 ohm-cm., while the original water had a resistivity of 18,000 ohm-cm. When an insulator was coated with this slurry and dried, measurements made of the surface conductivity and salt deposit density were the same as though the slurry contained a small amount of salt.

It was decided to repeat the tests with Kaolin and Bentonite to check the repeatability of the results when compared on the basis of salt in the slurry. The data obtained are reported in Table III where it is seen that the repeatability is as good as it was with Cab-O-Sil and Photo-Flo, but a better agreement is obtained when surface conductivity is considered (Figure #5).

NON-UNIFORM DISTRIBUTION OF THE CONTAMINANT

During laboratory tests all of the insulators of a string are usually coated in the same manner, and the individual insulators are also coated fairly uniformly. Under natural service conditions, however, the forces of wind, rain, gravity and the electric field (11) combine to produce a highly non-uniform coating that is generally more concentrated near the line end of the string and is usually denser near the cap and pin of the individual insulators (6).

Attempting to simulate all of these conditions in the laboratory is very difficult, but, in order to determine the influence of non-uniform distributions of contaminant, it was decided to analyze:

1. Non-uniform Distribution in the String: that is the insulators of the upper part of the string are coated with a slurry containing less salt than those in the lower part;

2. Non-uniform Distribution on the Insulators: that is the upper surface of each insulator is coated with a slurry containing less salt than the lower surface.

1. Non-uniform Distribution in the String:

In this investigation four different levels of salt content were used: a first series with 2 and 20 g/l and a second with 5 and 10 g/l. These numbers were selected to examine the influence of large and small differences in the slurry coatings. In each test nine contaminated insulators were used, but the number of them coated in the upper part of the string with less salt was varied. Tests were made with 1, 3, 5 and 7 insulators on the upper end coated with 2 g/l and the remainder in each case with 20 g/l. Tests were also made with 1, 4 and 7 insulators on the upper end coated with a 5 g/l slurry and the remaining insulators coated with 10 g/l.

All the test results are summarized in Figure #8 and in column 7 of Table IV. Because of the non-uniformity of the coating, the surface conductivity has no meaning, but it is possible to compare the results on the basis of the total conductance of the strings. The solid line of Figure #8 corresponds to the average withstand voltage obtained when the same slurry coats all the insulators, and the points A, B, C and D correspond respectively to the data obtained with 2, 5, 10 and 20 g/l of salt. The other points in the figure correspond to different coatings as indicated.

When the distribution of contaminant in the string is not uniform, the withstand voltage with the same total surface conductance is less than with uniform distribution. The maximum change with 5 and 10 g/l is at 4.6 μS, where the reduction is 11%; with 2 and 20 g/l it is at 3 μS, where the reduction is 36%. In both cases, the maximum reduction happens when about one third of a string is contaminated with the slurry having the lower salt concentration.

As already mentioned, in service installations the distribution of contaminant on the string is not generally uniform, whereas in artificial tests each insulator is coated in the same way with the same slurry. This could mean that withstand voltages obtained in artificial tests are higher than those that can be realized in service, even though the measured conductance is the same.

The ability of a non-uniformly contaminated string to hold a voltage depends upon the distribution of surface resistance. If all the parts of the string are able to withstand the voltages applied to them, there is a total withstand; when one of the parts flashes over, all the voltage is applied to the remainder of the string. A withstand or flashover results, depending upon the ability of the remainder of the string to support the voltage.

During the tests with 2 and 20 g/l of salt, the following succession of events was observed.

When voltage was applied to strings having the first insulator on the ground end coated with 2 g/l and the other eight with 20 g/l, activity started immediately on the lower surface and near the cap of the first insulator (Figure #9-1a) and then, with less intensity, on the lower surfaces of the other insulators (Figure #9-1b). The first insulator then flashed over and, depending on the applied voltage, the other insulators withstood (Figure #9-1c) or flashed over. When the number of insulators coated with a 2 g/l slurry was increased and those with 20 g/l correspondingly decreased, the activity throughout the whole test was concentrated only on the lower surfaces of the insulators coated with the lesser amount of salt. If these were able to withstand, there was a total withstand, otherwise there was first a partial and then a total flashover. A qualitative example is shown in Figure #9-2a, where the first three are coated with 2 g/l and the other with 20 g/l. At the end of each withstand test there was no visible activity except near the pin of the lowest insulator coated with the slurry having the lower salt content, where there was a characteristic blue scintillation.

When the 5 and 10 g/l slurries were used, the activity was generally the same as that described with the exception that when only one insulator was coated with 5 g/l and the rest with 10, the initial activity existed on the lower surface of all the insulators.

After the preceding qualitative test observations were made, it was decided to try to calculate the withstand values for the non-uniformly contaminated strings based upon the withstand values obtained for uniformly contaminated strings reported in reference (1).

Referring to Table IV the calculations were made as follows:

The data in column 4, the average surface resistance of the insulators coated with the various slurries, was calculated from the conductivity values given in Figure #10 of reference (1) and the form factor for the insulators. Thus, for a slurry of 10 g/l salt content the conductivity is 57 μS.

The conductance per insulator =

$$\frac{\text{conductivity}}{\text{form factor}} = \frac{57}{.774*} = 73.7\ \mu S$$

The resistance per insulator =

$$\frac{1}{\text{conductance/Ins.}} = \frac{1}{73.7 \times 10^{-6}} = 13{,}600 \text{ ohms}$$

Similarly for 5 g/l:

Resistance per insulator = 30,300 ohms.

* Calculated form factor for standard insulators.

For the case of 4 insulators coated with 5 g/l in series with 5 insulators with 10 g/l, the total string resistance is:

4 with 5 g/l = 4 x 30,300 ∼ = 121,200

5 with 10 g/l = 5 x 13,600 ∼ = 68,000

TOTAL = 189,200

of which the insulators coated with 5 g/l comprise 64% (column 4) and those with 10 g/l 36%. Thus, four of the insulators (column 8) withstood 64% of the applied withstand voltage or 39.6 kV as shown in column 9. From Figure #11, reference (1), however, assuming a linear relationship, four insulators coated with a 5 g/l slurry will withstand 35.2 kV (column 5). Thus, the withstand value, predicted on the basis of uniformly coated insulators, is 11% lower than the non-uniformly coated insulators (column 10). The other values in column 10 were calculated in a similar manner, and it can be seen that the withstand values could have been predicted in this manner with an error ranging from 2 to 14%.

The measured values of total conductance in these tests were about 7 to 8% less than calculated values deduced from data with the same slurry, but in spite of this there is a good agreement between the measured withstand voltage of a non-uniformly coated string and the voltage that can be predicted knowing only the surface resistances of the string and the withstand voltage per insulator when the same slurry is used. In this evaluation, it must be realized that the values of column 4 are calculated from average surface conductivities measured during a preceding investigation (1), and that the initial surface resistances measured at low voltage undoubtedly change a little when high voltage is applied.

From these tests it can therefore be concluded that a non-uniform distribution of contaminant on the insulators from one end of a string to another is more dangerous than a uniform distribution. This statement is in agreement with some conclusions deduced from Project EHV tests (6), and is in disagreement with another investigation carried out in Sweden on dc insulators (12).

2. Non-uniform Distribution on the Insulators:

Nine standard disk units were also used for this investigation, and slurries with 2, 5, 10 and 20 g/l of salt applied. The different coatings and the test results are reported in Table V and in Figure #10, but before discussing the results, it should be noted that the observed mechanism during the tests was completely different from those with non-uniform distribution along the string.

In the first three test series of Table V, where the contaminating slurry reached a maximum of 5 g/l on the upper surface and 10 g/l on the lower, the maximum activity was near the pin. This is normal for contamination tests in general and has been observed both in the laboratory and in the field. However, in the last two test series (5/20 and 10/20) the activity all occurred on the upper surface with none on the lower. After each withstand a completely dried ring was noted near each cap, while the other parts of the remaining surface were still wet. The width of these rings decreased going from insulators near the ground to those near the line. After each flashover these rings were deformed in some parts and the dry bands reached the outside edge of the insulators.

No particular investigation was made to explain these observations, but they can be attributed to the high voltage gradient near the cap and the greater current density near the pin. With a uniform contaminating coating, a distance near the pin that represents 22% of the leakage distance supports 70% of the voltage, and near the pin 6% of the leakage distance supports 23% of the voltage (6). Due to the small diameter of the pin, the current density is very high in this area. Under normal contamination conditions this results in a generation of heat around the pin, drying out the contamination, and forming a dry band which subsequently sparks over since most of the voltage appears across it. When a slurry of 20 g/l salt is used to coat the lower insulator surfaces, however, and one with only 5 or 10 g/l is used on the upper, the conductivity around the pin relative to that at the cap is increased to the point that dry banding occurs at the cap instead of at the pin.

In Figure #10 the withstand voltage of a nine insulator string is plotted versus total surface conductance with a solid line for those cases where the same slurry is used for both upper and lower surfaces. The points corresponding to withstand voltages with different slurries do not fall on this line: those of the first three test series being higher, and the other two being lower. The points of the first three test series are quite close to the average withstand voltages, the maximum deviation being 8%. The points of the fourth and fifth series, however, for which the activity around the cap occurred, differ from the average represented by the line by 15% and 21% respectively.

In columns 7 and 8 of Table V, the average withstand voltages when the same slurry coats the upper and lower surfaces are reported (1), and in columns 9 and 10 these values are compared with those of column 4 obtained with different slurries on the same insulator. Some interesting comparisons can be noted. When a slurry with 5 g/l on the upper surfaces and with 10 g/l on the lower surfaces is considered, the withstand voltage (column 4) is 14% lower than that obtained with a 5 g/l slurry on each surface (column 7); doubling the salt of the slurry on the lower surfaces, the withstand voltage decreases to 33% below that for the uniform slurry.

With a 2 g/l slurry on the upper surfaces and a 5 g/l on the lower surfaces (a 2.5 times change instead of 2 as above), the withstand voltage decreases 17% in comparison with a 2 g/l slurry on each surface; doubling the salt of the slurry on the lower surfaces, the withstand voltage again decreases to 33%. Thus the same action was duplicated for two salt concentrations; doubling the slurry salt for the lower surfaces approximately doubled the decrease in strength relative to the withstand for a uniform coating equivalent to that on the upper surface.

On the other hand if the withstand voltages for the salt on the lower surface is used as a basis for comparison (column 8), changing the slurry for the upper surface from 5 g/l to 2 g/l results in an increase in strength from 15% above that for a uniform slurry to 35% (column 10). If the 20 g/l coat on the lower surfaces is considered, however, the results are different. For a 10 g/l coat on the upper surfaces the strength is 19% below that for the uniform 20 g/l coating, whereas for 5 g/l on the upper surface the strength is 2% above that for the uniform coat. Although this observation is not consistent with the previous one, it is obvious that the salt concentration on the upper surface is affecting the withstand strength to almost the same degree as that on the lower surface. For the case of a 20 g/l slurry coating the lower surface, the degree of contamination is so heavy that the scintillation activity on the insulators shifts from the lower to the upper surface, and this undoubtedly accounts for the differences noted in the withstand values relative to a uniform coating.

Although a more extensive investigation is necessary, these tests indicate that for the wet contaminant test method both the upper and lower surfaces contribute in a similar way to determine the withstand voltage of a contaminated string. This conclusion is different from that obtained with another test method (3) in which contamination on the bottom surfaces was found as the major factor in contamination flashover. The reasons for this are not apparent at the present time.

TESTS ON HORIZONTAL STRINGS

In order to study the effects of geometrical position of a contaminated string on the withstand voltage by the wet contaminant method, both standard and fog units were tested with the original Cab-O-Sil slurry. Each string was first vertically contaminated and then pulled to the horizontal position without damaging the coating. For each test the surface conductivity and the salt deposit density of the lower, upper and total surfaces were measured. The test results are reported in Table VI where they are also compared with those of vertical strings coated with slurries of the same salt content. These latter data are taken from reference (1).

The salt deposit densities of the vertical strings are higher than those of the horizontals, and the differences are larger for the upper surfaces than they are for the lower. Although coated originally as uniformly as possible, the final coating existing on either the vertical or horizontal strings depends upon the run-off as the insulators hang waiting for test. The usual procedure is to wait until dripping stops before testing. It has been found on the vertical strings that the resultant salt deposit on the bottom surface of the insulators is generally less than that on the top and is usually about 1/2 of the top value. For the horizontal strings the average salt on top and bottom surfaces is almost equal, although by observation it can be seen that there is greater concentration on the lower portion of both. The makeup of the path that determines the total conductance, and thence conductivity, measured for the string is very complex. Thick layers of conducting material may contribute nothing to the conducting path if they are in series with even small high resistance elements. Accordingly, it becomes quite obvious that in the case of the horizontal string, where the flow of the coating is down towards the lower half, and the upper surface of the disk has almost the same salt density as the lower, the efficiency of the coating in forming a continuous conducting path will be greater than for the vertical string. Therefore, although the salt deposit densities are as much as 50% lower for the horizontal strings than for the vertical, the conductivities differ by less than 20%.

Comparisons of the withstand voltages can be made using several parameters to measure the pollution severity.

When the salt in the slurry is considered, the horizontal strings are electrically stronger than the verticals; the maximum values are 7 to 8% higher as shown in Figure #11. This is logical because both salt deposit density and surface conductivity are lower.

When the surface conductivity is used as the parameter, there is no difference between horizontal and vertical strings. In Figure #12 the dotted and solid line are the average withstand curves obtained with vertical strings, and the points for the horizontal strings are very close to them. This is another confirmation that when a string of insulators is coated with the same slurry, the withstand voltage is the same, within the usual accepted limits for a contamination test, for the same total surface conductance or conductivity of the string, and it is not dependent upon the test method, the contaminating slurry or the geometrical position.

In Figure #13 the withstand voltages are plotted versus the total salt deposit density for the two positions; in this case the vertical strings seem to be stronger than the horizontal. Whereas in Table VI the two string orientations are compared on the basis of the same salt in the slurry, in Table VII they are analyzed for equivalent withstand voltages. In Table VII the values for the horizontal strings are read from Table VI, whereas those for the vertical strings are read from curves plotted in Figure #13 for vertical strings and those of salt deposit density versus the salt in the slurry measured during a preceding investigation (1).

From this comparison it can be seen that the salt deposit density in the lower surfaces is very close for both standard and fog units with the greatest difference of about 15% occurring at 63 kV. Thus it is seen that the withstand voltages are approximately the same for the horizontal and vertical strings when the salt deposit densities on the lower insulator surfaces are the same. Since the salt deposit densities on the upper surfaces are different for the two string orientations, it appears that, contrary to the conclusion made earlier, the salt deposit density on the lower surface controls the withstand strength. The investigation, however, was not planned to investigate this point, and it is believed to be a coincidence resulting from the different distributions of the salt on the upper surfaces for the horizontal and vertical conditions. For example, it was noted that for the vertical hanging insulators a large concentration of salt occurred near the joint between the cap and the porcelain. This contributes appreciably to the salt deposit density, but probably affects the conductivity and withstand voltages very little. When pulled to the horizontal position, this excess slurry ran down the insulators and dripped off. Thus, although the salt densities measured differently for the two orientations, that which was effective in causing a flashover could have been the same. Considering these facts, it is the authors' opinion that the test results on the horizontal strings do not contradict the earlier conclusions reached relative to the effect of the upper and lower surface coatings on the flashover strength.

After these considerations it seems evident that no difference exists between the horizontal and the vertical strings when the salt deposit density on the lower surfaces or the surface conductivity are assumed as parameters; when the salt in the slurry is considered, the horizontal strings are electrically stronger only because both salt deposit density and surface conductivity are smaller due to surface run-off. As a matter of interest, in Figures #14 through #16 pictures taken during withstand and flashover tests on horizontal strings are shown.

Generally, under service conditions it has been seen that horizontal and inclined strings are electrically stronger than vertical strings in areas of heavy contamination. The reason for this is not that the flashover mechanisms are different, but that they wash better (6).

CONCLUSIONS

The results of each of the three investigations carried out have already been discussed in detail and the most important conclusions are summarized as follows:

1. The good reproducibility of the results achieved with the wet contaminant method is a characteristic of the test method and can be achieved with any contaminating slurry that will give a good insulator coverage and maintain a uniform wet condition for the required test time.

2. In order to achieve reproducible results over a period of time and also between laboratories, the contaminating materials must be pure materials that will not change in composition.

3. For all of the tests performed, both in this and two preceding investigations(1,2), the withstand voltage was found to be constant for a given surface conductivity. Thus the withstand voltage was found to be independent of test method*, the contaminating slurry, and geometrical position.

4. A non-uniform distribution of contaminant along an insulator string results in a lower flashover strength than a uniform distribution.

5. The withstand voltage of non-uniformly contaminated insulator strings can be predicted with acceptable accuracy on the basis of low voltage measurements on the string in question and the withstand values of uniformly contaminated strings.

6. The contamination level of both the upper and lower surfaces of an insulator affect the withstand strength.

7. The strength of horizontal and vertical strings of insulators are equivalent for equivalent contamination levels. The greater tendency of horizontal strings to clean themselves by dripping and washing can result in apparently greater strengths in field installations or when dipped in identical slurries.

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* Two test methods have been investigated by the authors, the wet contaminant and clean fog. The conclusion also holds true, however, for clean fog and salt fog tests performed in the CESI laboratory (13).

TABLE I

MAIN CHARACTERISTICS OF TESTED STRINGS

Insulator Type	Number of Units	Overall Length (mm)	Total Leakage Path (mm)
Standard Disk	9	1314	2630
Fog Disk	8	1320	3450

TABLE II

MAXIMUM AND MINIMUM PERCENTAGE PROPORTIONS OF MOST IMPORTANT COMPONENTS OF SOME KAOLINS & BENTONITES*

COMPONENTS	KAOLIN		BENTONITE	
	Maximum	Minimum	Maximum	Minimum
SiO_2	45.56	43.64	67.20	48.80
Al_2O_3	40.22	37.65	28.81	15.08
Fe_2O_3	1.44	.30	3.92	.10
Mg O	1.02	.08	7.84	1.01
$Ti\ O_2$	.37	0	.40	0
Na_2O	1.16	0	4.33	0

* These data are from tables in references (8) and (10).

TABLE III

TESTS WITH KAOLIN AND BENTONITE

COMPARISON OF TWO TEST CYCLES FOR VARIOUS SALT CONCENTRATIONS

		INSULATORS							
		Standard				Fog			
Salt in Mixture	(g/l)	1	2	5	10	1	2	5	10
Withstand Voltage First Test	(kV)	158	107	75	60	166	140	86	74
Withstand Voltage Repeated Test	(kV)	170	113	77	58	154	128	90	68
Percentage Change of Repeated Test with Respect to the First	(%)	+8	+6	+3	-4	-7	-9	+5	-8

TABLE IV

NON-UNIFORM DISTRIBUTION OF CONTAMINANT IN THE STRING

1	2	3	4	5	6	7	8	9	10
Type of Slurries	Number of Insulators Coated with Mix 1	Number of Insulators Coated with Mix 2	Calculated average surface resistance of the part of string coated with Mix 1 (%)	Calculated average voltage that the part of string coated with Mix 1 is able to withstand (kV)	Calculated average voltage that the part of string coated with Mix 2 is able to withstand (kV)	Tested withstand voltage of complete string (kV)	Number of insulators that supported the highest part of voltage	Calculated voltage withstood from the part of string that supported the highest part of voltage (kV)	Percentage change of values of columns 5 or 6 with respect to those of column 9 (%)
Mix 1 = 2 g/l Mix 2 = 20 g/l	1	8	63	13.4	46.2	47	8	47.0	2.0
	3	6	87	40.2	34.6	54	3	47.0	14.5
	5	4	94	67.0	23.1	80	5	75.2	11.0
	7	2	98	93.8	11.5	104	7	102.0	8.0
Mix 1 = 5 g/l Mix 2 = 10 g/l	1	8	22	8.8	52.5	58	8	58.0	9.5
	4	5	64	35.2	32.8	62	4	39.6	11.0
	7	2	89	61.6	13.1	74	7	65.8	6.5

TABLE V

NON-UNIFORM DISTRIBUTION OF CONTAMINANT IN THE INSULATORS

1	2	3	4	5	6	7	8	9	10
Test Series Number	Coating Slurry of Upper Surfaces	Coating Slurry of Lower Surfaces	Withstand Voltage	Salt Deposit Density Upper Surfaces	Salt Deposit Density Lower Surfaces	Average Withstand Voltage with the Same Slurry as Upper Surfaces	Average Withstand Voltage with the Same Slurry as Lower Surfaces	Percentage Change in Withstand Voltages - Comparisons Columns 4 & 7	Percentage Change in Withstand Voltages - Comparisons Columns 4 & 8
	(g/l)	(g/l)	(kV)	(mg/cm^2)	(mg/cm^2)	(kV)	(kV)	(%)	(%)
1	2	5	100	.024	.030	120	79	-17	+27
2	2	10	80	.024	.060	120	59	-33	+35
3	5	10	68	.060	.060	79	59	-14	+15
4	5	20	53	.060	.120	79	52	-33	+2
5	10	20	42	.120	.120	59	52	-29	-19

TABLE VI

Type of Disk Insulators	Salt in Slurry	HORIZONTAL STRING					VERTICAL STRING				
		Average Surface Conductivity	Average Salt Deposit Density Lower Surfaces	Average Salt Deposit Density Upper Surfaces	Average Salt Deposit Density Total Surfaces	Withstand Voltage	Average Surface Conductivity	Average Salt Deposit Density Lower Surfaces	Average Salt Deposit Density Upper Surfaces	Average Salt Deposit Density Total Surfaces	Withstand Voltage
	(g/l)	(μS)	(mg/cm^2)	(mg/cm^2)	(mg/cm^2)	(kV)	(μS)	(mg/cm^2)	(mg/cm^2)	(mg/cm^2)	(kV)
Standard	2	8	.009	.012	.010	122	9	.012	.024	.018	120
	5	21	.021	.028	.023	85	25	.030	.060	.044	79
	10	45	.041	.054	.045	63	53	.060	.120	.088	59
Fog	5	18	.018	.028	.021	102	20	.019	.057	.030	96
	10	36	.035	.054	.037	79	43	.038	.114	.060	73

TABLE VII

Type of Disk Insulators	Withstand Voltage (kV)	SALT DEPOSIT DENSITIES HORIZONTAL STRING Lower Surfaces (mg/cm^2)	HORIZONTAL STRING Total Surfaces (mg/cm^2)	VERTICAL STRING Lower Surfaces (mg/cm^2)	VERTICAL STRING Total Surfaces (mg/cm^2)
Standard	63	.041	.045	.048	.070
Standard	85	.021	.023	.023	.033
Standard	122	.009	.010	.011	.017
Fog	79	.035	.037	.034	.050
Fog	102	.018	.021	.019	.029

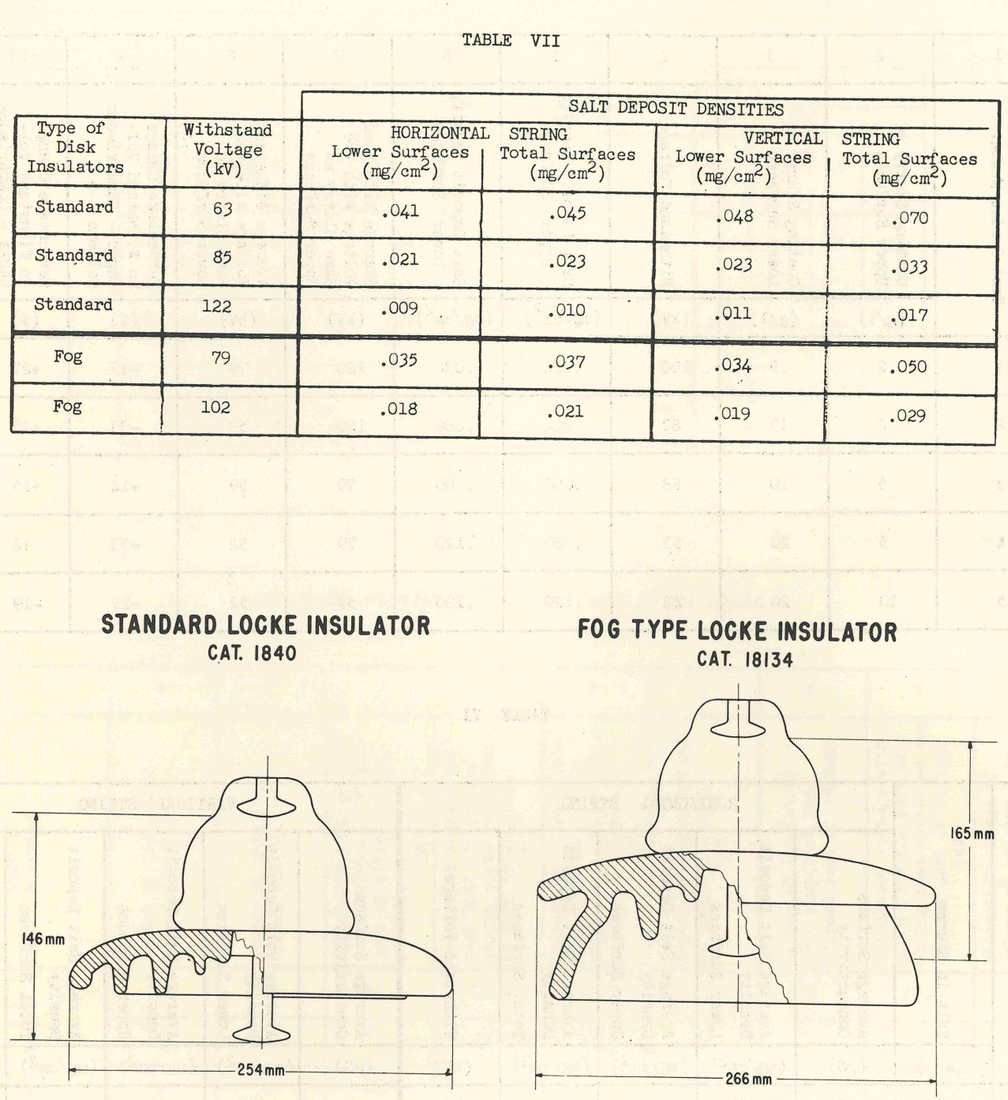

Fig. 1. Tested Insulators.

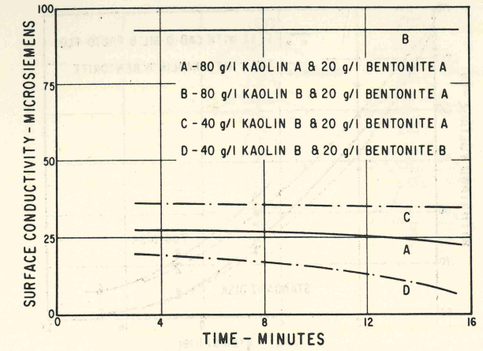

Fig. 2. Influence of Kaolin and Bentonite Types on the Surface Conductivity. Slurries with 5 g/l of Salt.

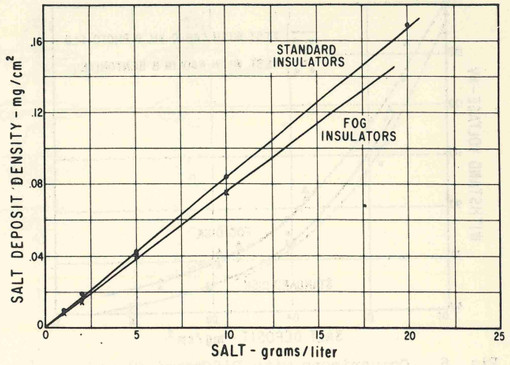

Fig. 3. Slurries with Kaolin and Bentonite. Total Salt Deposit Density Versus the Salt in the Mixture.

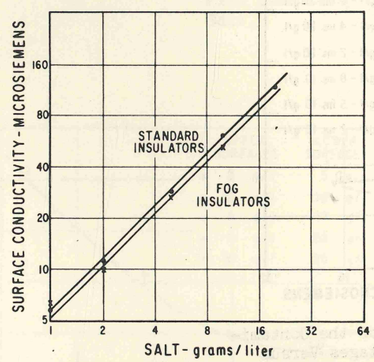

Fig. 4. Slurries with Kaolin and Bentonite. Initial Surface Conductivity Versus the Salt in the Mixture.

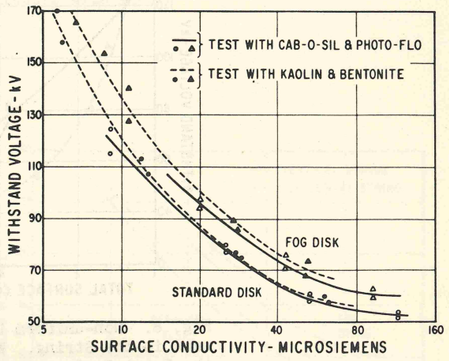

Fig. 5. Comparisons with Different Slurries. Withstand Voltages Versus the Initial Surface Conductivity.

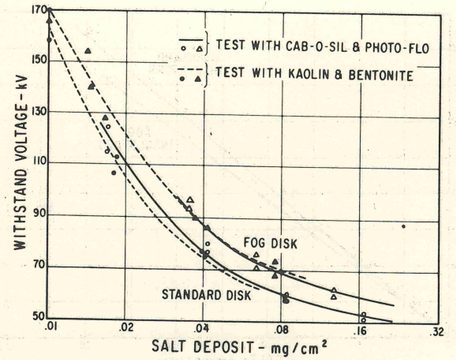

Fig. 6. Comparisons with Different Slurries. Withstand Voltages Versus the Total Salt Deposit Density.

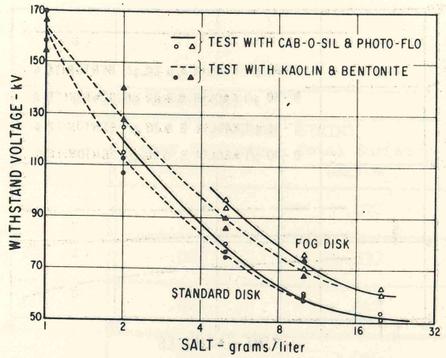

Fig. 7. Comparisons with Different Slurries. Withstand Voltages Versus the Salt in the Mixture.

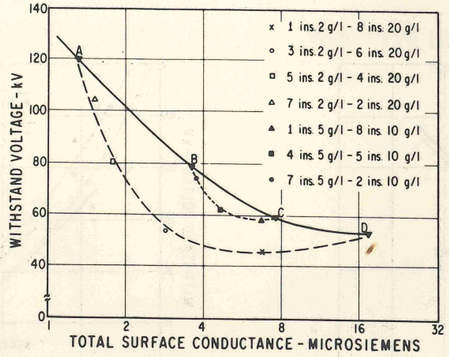

Fig. 8. Non-uniform Distribution of the Contaminant in the String. Withstand Voltages Versus the Total Surface Conductance. The Letters A, B, C, D Represent the Points Obtained for Uniform Slurry Coatings of 2, 5, 10 and 20 g/l Salt Respectively.

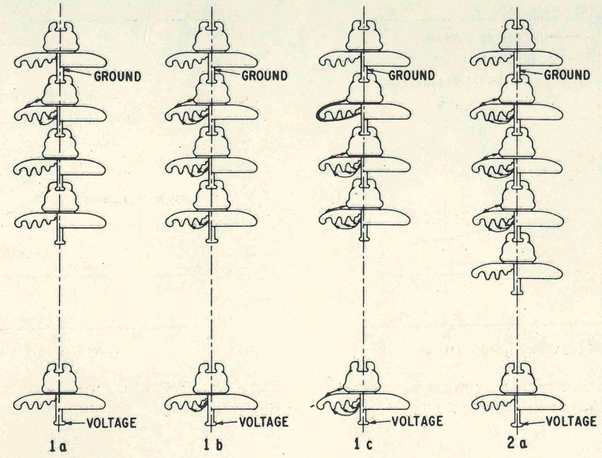

Fig. 9. Visual Observed Mechanism During Withstand Tests with Non-uniform Distribution of the Contaminant in the String:

1. First Insulator at Ground End Coated with Less Salt, Other Eight Insulators with More Salt.

2. First Three Insulators from Ground End Coated with Less Salt, Other Six Insulators with More Salt.

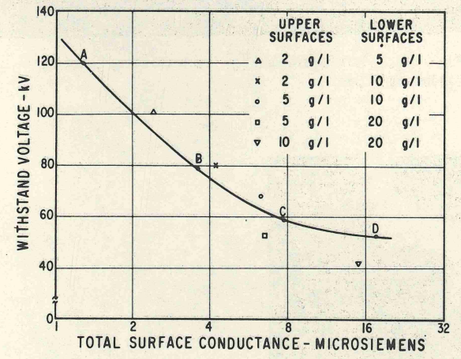

Fig. 10. Non-uniform Distribution of the Contaminant in the Insulators. Withstand Voltages Versus Total Surface Conductance. The Letters A, B, C, D Represent the Points Obtained for Uniform Slurry Coatings of 2, 5, 10 and 20 g/l Salt Respectively.

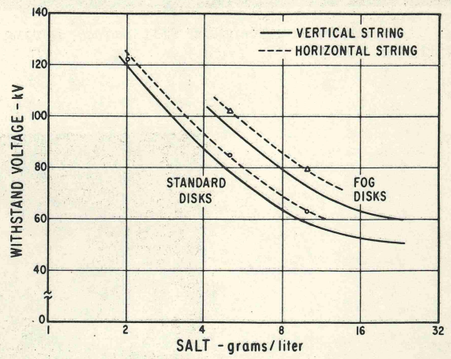

Fig. 11. Vertical and Horizontal Strings. Withstand Voltages Versus Salt in the Mixture.

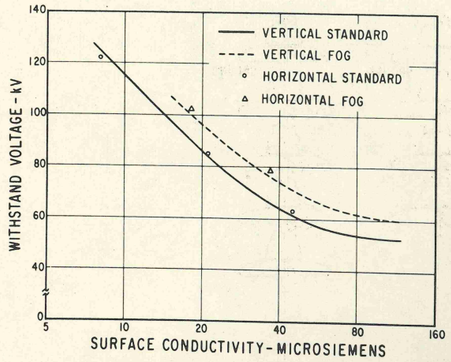

Fig. 12. Vertical and Horizontal Strings. Withstand Voltages Versus Surface Conductivity.

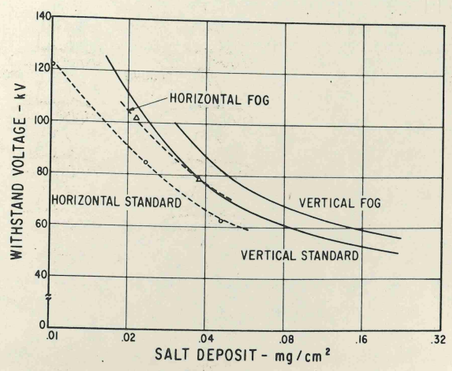

Fig. 13. Vertical and Horizontal Strings. Withstand Voltages Versus Total Salt Deposit Density.

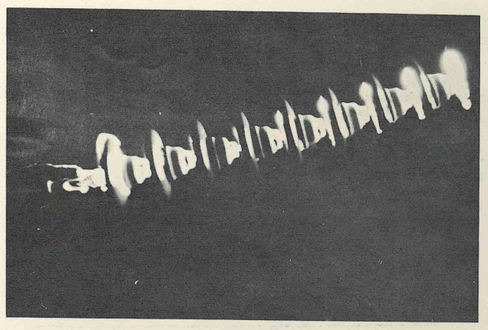

Fig. 14. Horizontal Standard Unit String During a Withstand Test.

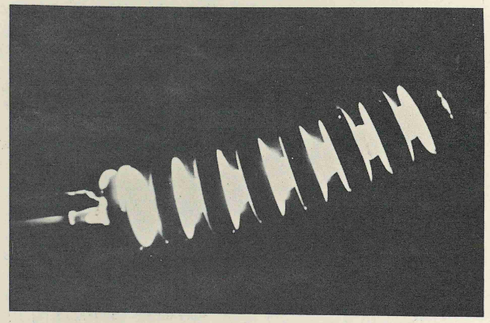

Fig. 16. Horizontal Fog Unit String During a Withstand Test.

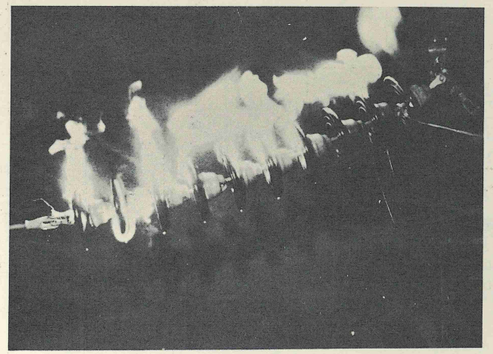

Fig. 15. Horizontal Standard Unit String During a Flashover Test.

Transactions Paper

(Reviewed and Accepted for Publication)

DISCUSSION IN QUADRUPLICATE DUE July 11, 1969.

A STUDY OF SOME VARIABLES AFFECTING CONTAMINATION TESTING USING THE WET CONTAMINANT METHOD

B. Macchiaroli
Institute of Electrical Engineering
University of Naples
Naples, Italy.

F. J. Turner
Senior Member IEEE
General Electric Company
Pittsfield, Mass.

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Paper No.
69 TP 692 - PWR

INSULATOR CONTAMINATION - PROBLEMS AND TESTS

F. J. Turner

I. INTRODUCTION

II. GENERAL PROBLEMS

- A. To Simulate or Not to Simulate Nature
- B. Measurements of Degree of Contamination
- C. Selection of Contamination Materials
- D. Method of Moisture Application

III. POPULAR PRESENT DAY CONTAMINATION TEST METHODS

- A. Salt Fog Test
- B. Predeposit Test
  - 1. German method
  - 2. Dipping method
  - 3. Flow-coating
- C. ASEA Test Method
- D. Wet Contaminant Method

IV. SUMMARY

- A. Utility of Various Test Methods
- B. Correlation With Natural Conditions
- C. Need for Both Development & Practical Test Methods

SALT FOG METHOD

1. Insulators thoroughly cleaned.

2. Hung in suitable test chamber with a voltage source.

3. Voltage applied at a specified value - usually the insulator service value.

4. Salt fog introduced into chamber of a specified salinity measured in grams of salt per liter of water.

5. Voltage is held constant for one hour, and if no flashover occurs test is called a withstand.

6. Test is repeated at a higher or lower salinity depending on whether a withstand or flashover was obtained.

7. Insulators are evaluated on the basis of highest salinity fog withstood for one hour. Three withstands out of four tests at a given salinity are required to determine the maximum withstand.

8. Nozzle size, number of nozzles, distance to test insulators, rate of liquid flow are all controlled.

PREDEPOSIT METHOD

German Method

1. Insulators are thoroughly cleaned and dried.

2. Insulators are uniformly spray-coated with a mixture of Kieselguhr and salt in water.

3. The insulators are dried.

4. The dried insulators are placed in a fog chamber and service voltage applied.

5. Fog of approximately the same conductivity as the insulator would experience in service is then created in the room.

6. As the fog density increases the insulator leakage current will start to increase and will finally level off at the maximum conduction state.

7. Voltage is increased until failure occurs.

8. The increase in voltage above the service voltage is a measure of the margin the insulator has above its operating voltage for the contamination applied.

Remarks

Many variations of the German test have developed. Most investigators object to the flashover type of test method in that it does not give the insulators time to cook and form dry bands which can precipitate a flashover. Accordingly a withstand type of test is usually performed.

For applying the contaminant dipping is often preferred to spraying because of the difficulty in obtaining a uniform spray-coating. Recently flow-coating has been substituted for dipping in cases where size and geometry have made dipping impractical. Variables that have to be specified in order to obtain reproducible results are number, design and location of nozzles and circulation of fog in the tent. In the CESI laboratory they recently made similar tests in

which they pre-wetted the insulators completely in order to obtain a conductivity measurement. For the current development testing being performed at UHV, steam is generated to supply the fog for wetting the insulators rather than using air pressure to atomize a water stream.

ASEA TEST METHOD

1. Insulators are cleaned and dried.

2. Insulators hung in test chamber and test voltage is applied.

3. One kilogram of Kaolin dust is blown into the test chamber.

4. After 30 minutes the voltage is removed and 10 liters of water containing 0.5% NaCl are atomized and blown into the chamber during a 30 minute period.

5. Voltage is again applied to the insulators and a second 10 liters of water vapor containing 0.5% NaCl are blown into the chamber during a 30 minute period. Current pulses and flashovers are recorded.

6. If no flashover occurs the insulators are dried for about 3 hours and the cycle repeated without cleaning the insulators.

7. The number of test cycles until flashover occurs is a measure of the insulator performance.

WET CONTAMINANT METHOD

1. Thoroughly clean and dry the insulators.

2. Flow-coat the insulators with a contaminating slurry. A preferred slurry contains 20 g/l of Cab-O-Sil HS-5, 1 g/l of Photo-Flo 600, and salt to obtain the desired conductivity.

3. Three to five minutes after the flow-coating is completed apply the specified voltage to the insulators and hold until all scintillation ceases or a flash-over occurs.

4. Repeat the above cycle twice. Three withstands are necessary at a given voltage level in order to certify that it is a withstand.

5. If a maximum withstand voltage is desired it is customary to raise the voltage steadily up to flashover on the first test and then drop down 10% from the flashover level for the second test. Subsequent tests are performed by changing the voltage in 5% steps depending on whether withstand or flashovers are obtained. Once again, three withstands are necessary in order to establish the withstand voltage level.

6. Levels of contamination can be specified by the salt concentration in the slurry, the conductivity of the slurry, the conductivity of the insulator string before test, or the salt deposit density on the insulator surface.

TA-264(1-61)

GENERAL ELECTRIC

COPIES:

DEPT.—LOCATION—DATE

High Voltage Laboratory
Pittsfield, Mass. & Philadelphia, Pa.
September 25, 1969

SUBJECT

Transmission System Contamination Symposium
September 23, 1969

Gentlemen:

In reviewing the Symposium with people who attended, I received the distinct impression that it was a worthwhile endeavor and that there was a cross fertilization of information and ideas concerning the subject which will benefit the General Electric Company.

Mr. A. Glassanos' welcoming address fairly well set the tone for the program which followed and it was very ably summarized by Dr. T.H.Lee.

In trying to concisely state the outcome of the Symposium we -

1. Agree that we should watch the standardization activities very closely.

2. That some additional research and development work would be very desirable in this area, particularly as this type of a problem can become significant without prior warning of its inception.

3. That future symposiums on this or other subjects of common interest would be worthwhile.

We want to particularly thank the people who contributed to the program. Their presentations were well thought out and stimulating. This is the secret of a worthwhile meeting.

Very truly yours,

G.W.Alexander - Manager
High Voltage Laboratory - Pittsfield

T.W.Liao - Manager
High Voltage Laboratory - Philadelphia

/n

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J.Church	High Voltage Lab. - Pittsfield	8-234-2065
C.R.Craig	I&P Cap. Dept. - Hudson Falls	8-232-8385
C.D.Croskey	IPD - Baltimore, Md.	8-272-9294
J.C.Devins	R&DC - Schenectady	8-235-6541
N.E.Dillow	IPD - Pittsfield	8-234-5381
J.K.Easley	IPD - Pittsfield	8-234-5372
W.H.Eason	DPED - Pittsfield	8-234-2766
A.Glassanos	PT Eng. - Pittsfield	8-234-2480
N.A.Hoglund	High Volt. Lab. Philadelphia	8-245-3272
A.L.Jenny	High Voltage Lab. - Pittsfield	8-234-2773
J.M.Jetsako	IPD - Baltimore	8-272-9230
I.B.Johnson	EUEO - Schenectady	8-235-5447
M.Kawai	Project UHV - Pittsfield	8-234-3460
W.A.Keen Jr.	IPD - Pittsfield	8-234-5377
A.R.Koerber	DPED - Pittsfield	8-234-2401
T.H.Lee	High Power Lab. - Philadelphia	8-245-3220
R.H.Lester	IPD - Baltimore, Md.	8-272-9321
T.W.Liao	High Volt. Lab. - Philadelphia	8-245-3221
A.L.Libby	IPD, Baltimore, Md.	8-272-9235
K.N.Mathes	R&DC - Schenectady	8-235-2595
F.S.Nichols	M&T Lab. - Pittsfield	8-234-2880
H.W.Oksala	High Volt. Lab. - Pittsfield	8-234-2442
M.G.Ouellette	IPD - Pittsfield	8-234-5388
C.D.Palser	A.D. Guelph	
K.W.Priest	EUEO, Schenectady	8-235-9163
C.Ratliff	PCB - Philadelphia, Pa.	8-245-2434
A.F.Rohlfs	High Volt. Lab. - Pittsfield	8-234-2447
E.C.Sakshaug	DPED - Pittsfield	8-234-2337
M.A.Sargent	High Volt. Lab. - Pittsfield	8-234-2898
P.V.Shade	ATBS - Pittsfield	8-234-5380
A.H.Sharbaugh	R&DC - Schenectady	8-232-6537
R.B.Stetson	Meter - Somersworth, N.H.	8-262-5478
M.M.Solomon	AMTL - Philadelphia	8-245-3253
H.H.Taj	IMD - Schenectady	8-235-3795
A.F.Touchette	Meter - Somersworth, N.H.	8-262-5395
F.J.Turner	High Volt. Lab. - Pittsfield	8-234-2478
E.R.Uhlig	PT Eng. - Pittsfield	8-234-3327
W.Vandergrift	PTD - Pittsfield	8-234-3416
F.C.Vose	IPD - Baltimore	8-272-9222
R.A.Ward	IMD - Schenectady	8-235-2431
R.Weller	IPD - Baltimore, Md.	8-272-9226
W.A.Wesley	Apparatus - Peterborough	8-268-3612
E.S.Wheeler	IPD - Baltimore, Md.	8-272-9320
R.W.Williams	IMD - Schenectady	8-235-3793
D.D.Wilson	EUEO - Schenectady	8-235-4165
L.E.Zaffanella	Project UHV - Pittsfield	8-234-3465

FIELD AND LABORATORY TESTS OF CONTAMINATED INSULATORS FOR THE DESIGN OF THE STATE ELECTRICITY COMMISSION OF VICTORIA 500 KV SYSTEM

J. Johnson* R. T. Henderson* W. S. Price**

D. E. Hedman*** F. J. Turner ****

In recent years, the control of switching surges by circuit breaker resistors, and the use of shielding angles adequate to reduce lightning impulse flashovers, has made possible appreciable reduction in transmission line insulation levels and cost, particularly on EHV lines. As this process continues, additional design data will be required for the power frequency withstand of line insulators exposed to contamination, if future line designs are to be both successful and economical.

Although extensive investigations have been made during the past two decades on the power frequency performance of contaminated insulators, the basic mechanism is so complex, and there are so many parameters, known and unknown, in the problem that much work remains to be done to permit optimum line design.

Since the future 500 kv transmission system of the State Electricity Commission of Victoria must traverse a very severe contamination area, as indicated by present 220 kv line performance, a very extensive investigation has been made, including both field and laboratory work. This work provided a substantial amount of new design information for the 500 kv system. Details of this study are presented in this paper, for comparison with previous investigations, and possibly to serve as a basis for future research.

FIELD EXPERIENCE

The State Electricity Commission of Victoria supplies virtually all the electric power in the State of Victoria, an area of some 88,000 square miles in the southeastern corner of Australia. Apart from small hydroelectric stations contributing to peak load demands, and a low load factor entitlement from the Snowy Mountains Scheme, the bulk of the power is generated by base load thermal stations situated on the very extensive lignite brown coal fields of the Latrobe Valley, about 90 miles east of the capital city of Melbourne.

Since the first thermal station was installed in 1924, the total capacity of the Latrobe Valley generation has grown to its present level of some 1,400 MW, with a further 1,700 MW of plant under construction or on order, and the probability of extensive additions in the future.

* State Electricity Commission of Victoria, Melbourne, Australia.
** Bechtel Corporation, San Francisco, California.
*** General Electric Co., Schenectady, New York.
**** General Electric Co., Pittsfield, Massachusetts.

Initial transmission of power from the Latrobe Valley to Melbourne was by way of four 132 kv steel tower lines which have subsequently been supplemented by six 220 kv lines, and the S.E.C.V. is currently constructing the first of two 500 kv lines which will operate initially at 220 kv and finally at 500 kv in 1970.

If brown coal retains its present economic advantage over other fuels, then it is possible that a total of ten 500 kv lines will be required between the Latrobe Valley and Melbourne by the turn of the century, transmitting a total of some 19,000 MW of base load power, and it was primarily this factor and the associated problems of line easements which influenced the adoption of 500 kv as the next step in voltage.

The original 132 kv transmission lines, and the four 220 kv lines installed between 1956 and 1964 leave the power stations in a westerly direction towards Melbourne, the first 20 miles being located in a shallow valley. The prevailing easterly winds of the dry late summer and early autumn blow the power station plumes along the route of the lines, and the effects of pollution fall-out are readily seen on the insulators up to some 20-25 miles from the stations.

With the assistance of occasional live-line washing in later years, eight 5" x 10" porcelain standard cap and pin insulators on the 132 kv lines and fifteen 5" x 10" standard glass insulators on the 220 kv lines provided effective insulation, even near the power stations. No flashovers due to pollution were experienced, despite the increasing level of pollution, until late 1960 when a trial burning commenced with coal from a newly developed open cut.

In the first three months of 1961 a total of 28 flashovers occurred on the lines in foggy weather, 10 of them being experienced in a single period of one hour between 6 A.M. and 7 A.M. In this latter period, there was a cascade outage of all four 132 kv lines, and it was strongly suspected that the source side transient following upon a fault on one line led to the cascade tripping of the remaining healthy lines. All flashovers occurred on vertical (suspension) strings, and immediate action was taken to secure the lines by the hand application of 0.1 lb. of silicone grease (Dow Corning 5) per insulator on the suspension strings over the first 4-5 miles from the stations. Further greasing has been carried out as flashovers extended beyond the protected zone to a distance of some 10 miles. A total of nearly 90 line outages have occurred during the past five years and all were beyond the zone of protective grease. No pollution flashovers have occurred on greased insulators, which indicates that the protective life of the grease is still effective after three years of service. Strain strings have not been greased and no cases of flashover on these strings have been reported.

FIELD INVESTIGATIONS AND LABORATORY TESTS IN AUSTRALIA

Because of the serious effect of this pollution on the base load transmission, a very thorough field investigation was then started, which led to further tests in laboratories in both Australia and the U.S.

The prime objective of this work was determination of the insulation level to be used for 500 kv lines operating in heavily polluted areas, it being decreed that silicone grease coating is not a solution to the problem until more economic methods of application and maintenance are available.

Better knowledge of the basic mechanism of this type of insulator flashover was a secondary but most important objective.

The field investigations were directed toward:

1. The nature of the pollution and the development of an artificially polluted insulator having characteristics similar to those polluted in the field.

2. Field observation of the flashover phenomenon.

The Pollution

It was very quickly established that the flashovers were associated with the burning of coal from the new Morwell field and that this coal had a much higher proportion of sodium, chlorine, and sulphur than the coal from the earlier Yallourn field. It was also found that the majority of the undeveloped coal fields had similar salty coals, and, therefore, the problem would increase in its magnitude. Plant operating data is given in Table I and the fuel analysis of the two coals is given in Table II.

Many strings removed after flashover were subjected to a "swab" test. From each portion of the disc the pollution was removed by scraping and washing, then filtered, and the conductivity of the measured volume of liquid was determined. From curves of conductivity against per cent solubility the mass equivalent of salt (Na Cl) producing the same conductivity was determined. Typical conductivities are shown in Table III, together with chemical analysis of the pollutants.

Visual examination showed that the deposits of pollution were much heavier on the underside, or protected area, of the insulators and this has been attributed to the combination of electrostatic precipitation and the poorer natural washing of this side of the insulator. It was found, also, that heavier pollution occurred on the downstream side of strain strings, and this appears to be caused by eddying of the flue gases around the insulator under conditions of light wind.

It was observed that at least 4-5 hours of fog conditions prevailed before flashovers commenced, and thereafter the lines continued tripping out for two or three hours - a total of 21 outages occurring in one two-hour period. This process contrasts with coastal salt pollution which is dissolved off the discs much more rapidly in wet or foggy conditions, and if flashovers are going to occur, they take place soon after the right climatic conditions arise.

From this, it was deduced that the pollution had a slow release characteristic for the conducting salts, and that the solubles were bonded to the insulator by a cement-like residue. To obtain some guide to the characteristics, a number of polluted insulators were removed from the line and were placed in a test chamber 10' x 6' x 7'6" high, the thick porous walls of the chamber providing a good measure of temperature and humidity stabilization. The insulators were assembled as vertical strings of eight units and, to simulate clean fog conditions in the field, were left overnight in a relative humidity of nearly 100%. An electronic megohm meter operating from 10 volts d.c. was connected by screened leads to the two ends of the string, and insulation resistance measurements were taken.

Controllable low-pressure steam was injected into the chamber and fans, coolers and moisture-absorbent screens were used to stabilize the temperature and humidity over a five to eight hour test. Insulation resistance measurements were taken at regular intervals, and the average resistance per disc against time from inception of fog was plotted to give Curve A, Fig. 1.

Similar tests were made with clean insulators dipped in salt solution and it was found that there was a radical difference (as shown in Fig. 1, Curve C) between the release characteristics of the power station pollution and natural salt.

To simulate the natural slow release characteristics, the artificial salt pollution was bonded with fresh Portland cement until a curve was obtained which corresponded to that of the naturally polluted insulator. This was achieved by dipping a clean disc in a slurry containing, by weight, 5% to 10% salt in the water used: bonding was provided by adding two parts of cement to five parts of the water in every case. Alternatively, three dips in a 2% salt slurry with drying intervals between dips provided a suitable consistent coating. The insulation resistance-time curve of the artificially polluted insulators is also shown in Fig. 1, Curve B.

It was believed that an equivalent artifically polluted insulator had now been obtained, and this has formed the basis of subsequent tests carried out in Australia and America.

However, it was realised that true comparability with a naturally polluted string at the time of flashover may not have been achieved, because it was usually not possible to remove an insulator from an operating line immediately at time of flashover, and therefore the degree of pollution at that instant was not known - further leaching of solubles occurring in the interval before removal. Secondly, the tests had been carried out in clean fog, whereas it was highly probable that the fog droplets at the power station became conducting while in the plume of the flue gases, and the effect of this on the flashover was not known.

It was found that naturally polluted strings of insulators could not be made to flash over under clean fog conditions at service voltage and that it was necessary to contaminate the fog by the addition of salt. However, it was believed that by

varying the salt contamination of the artifically polluted insulators or the salt content of the fog, service flashover conditions could be simulated. For practical reasons the fog was kept clean, and a degree of salt contamination on insulators was established to give approximately the same performance as naturally polluted insulators in polluted fogs in the field. This degree of contamination was then used in laboratory tests.

Field Observations of Surging

Concurrently with the investigation into the pollution, an attempt was made to determine the mechanism of flashover on the suspension strings on the lines. Observers were stationed along the lines at the onset of the autumnal fogs, and the following visual information was obtained:

1. During high rates of moisture release, pear shaped drops have been seen which elongated from the rim and ultimately disappeared with a bright flash between the outer edges of the insulators spaced five inches apart.

2. Shortly after the onset of the fog, a continuous glow developed at the pins and flickering arcs were seen between a pair of outer skirts on the undersides of all insulators with the exception of the line end and upper two insulators of the vertical string.

3. After the fog had persisted for some hours, a change in the phenomenon occurred. The glow at the pins increased in intensity in the lower half of the string, and this was followed by tongues of arcing of increasing luminosity on the undersurfaces of the insulators, and reaching from the pins to the outer edges. A few momentary flashes would occur between separate pairs of insulators and then a bright yellow flash would envelop the lower two-thirds of the string, but without producing complete flashover and resultant line tripout. All glowing and arcing would then cease. This cycle would recommence after several minutes. No arcing was observed on the top sides of the insulators.

4. The arcing described in (3) only occurred under reasonably still atmospheric conditions. It was noted that the arcing immediately became quiescent as soon as the wind velocity exceeded about 5 mph.

   Figure 2 shows a composite record of the meteorological conditions which existed during typical periods when line flashovers occurred, and clearly indicates the effect of wind upon surging and flashover.

5. No more than a faint glow at the pins has been seen on strain strings with the insulators in horizontal arrangement, even during the periods when suspension strings in the same area were undergoing severe arcing. Although no extra insulators were used in the strain strings, and no silicone grease has been applied, no flashovers have ever occurred on these strings.

It was apparent that thermal effects were of considerable importance, and it was reasoned that dry banding was occurring, and that this was appreciably influenced by heat locked up in the vicinity of the cap and pin. This would explain the change to quiescent state at the onset of light winds. It was deduced from the abovementioned observations and the superior performance of the strain strings, where the heat could be naturally convected away from the vicinity of the cap and pin, that flashover was partially dependent on the orientation of the insulators.

Further investigation was obviously required into the mechanism of flashover, and steps were then taken to record the leakage currents on insulators on the lines which were in service, and also to carry out tests on naturally and artifically polluted insulators in a fog chamber with an attempt to propagate flashovers on test strings.

Field Measurements

As a first step towards investigating the mechanism of flashover, it was decided to monitor the leakage currents on the insulator strings on the lines in an attempt to determine the behavior of the insulators at the time of flashover.

At many points of typical pollution conditions along the line route, an extra insulator was inserted at the ground end of a string of insulators. A lightly insulated lead was taken from the pin of this isolating insulator through a protective metal tube clear of power arcs, and thence to the base of the tower. A protective ring spaced about one half an inch above the top side of the second disc from the ground end was provided to terminate power arcs at flashover. Experience has shown that this ring has proved to be effective in taking the power arcs to earth via the lead conduit and safeguards test personnel and equipment. The monitoring lead was taken down the tower to a shorting box near the base and, from these boxes, leads were run back to a test hut in which were located the recording instruments. Graded devices were used to protect against excessive voltage rises should a string develop a power arc.

Initially, chart type pen recorders were used to obtain records of periods at which high leakage currents and surging occurred, and these were started up where prior warning of temperature inversion and probable fogs had been received. It was found that, after some time had elapsed from the start of the fog, the leakage current rose to a steady value of about 2 milliamperes, and then, as moisture began to flow, the insulators went into bursts of surging.

There did not appear to be much difference in the surging records of strain strings and suspension strings, although in the case of the former the high surging commenced earlier without propagating to flashover, and in the case of the suspension strings the surging was delayed, but flashovers eventually occurred.

Attempts were made to obtain more suitable records of the surging currents by the development of transistorized surge counters, in which the triggering amplitude and duration of surge-burst response were independently adjustable. Records

showed that quite high random peaks of surging were occurring on operational lines without flashovers taking place, which showed that not all requirements for flashover were present and that some mechanism, possibly thermal, was operating to inhibit string flashover.

Because the transient surge pulses are too fast for analysis by eye on an oscilloscope, oscillographic photography was employed at selected test points, and the basic wave form of the surge current was found to be as shown in Fig. 3.

It soon became apparent that it would not be possible to determine the mechanism of flashover in a reasonable time from records on operational lines, because of the short annual periods of fog and the dangers inherent in reducing the insulation levels to give forced flashovers. Therefore, further investigations were started, in the laboratory with artificially polluted insulators, and in the field by converting one of the 132 kv lines to a test line with strings of differing creepage lengths and arranged in suspension, strain and inverted vee configuration.

Laboratory Tests

Strings of polluted insulators removed from the line and strings of artificially polluted insulators were placed in a fog chamber and voltage was applied with leakage currents being monitored.

Invariably, after a momentary burst of minor surging at the onset of wetting, these strings have withstood about twice service voltage without further surging. As the rate of fog injection was reduced, permitting dry band formation, some minor surging was resumed.

The addition of salt or very dilute H_2SO_4 in the mist readily produced severe surging at field voltage, providing the rate of wetting was sufficiently reduced to permit dry band formation.

Moving film oscillograph records of surge currents and applied voltages during these tests showed that, at each high current surge, the applied voltage had collapsed sufficiently to inhibit flashover. To obtain string flashover during severe surging, it was necessary to raise the voltage considerably, producing a conduction (leakage) flashover, rather than one due to successive voltage fluctuations as in critical surging. For this reason, it was concluded that critical surging tests could only be carried out by a laboratory with ample test capacity or in the field by reducing insulation, thus eliminating the effect of voltage sagging at each surge crest.

The laboratory tests did, however, establish a basic method for carrying out the tests and indicated the importance of the correct degree of wetness in producing dry banding and critical surging.

PITTSFIELD HIGH VOLTAGE LABORATORY TESTS

In order to establish the insulation level needed for the S.E.C.V. 500 kv transmission system between the Latrobe Valley coal fields and the Melbourne area, extensive tests were made on artificially contaminated insulators in the High Voltage Laboratory of the General Electric Company in Pittsfield, Massachusetts.

These tests, which were firmly based on the field and laboratory work carried out in Australia, had the following objectives:

1. Determine the relationship between flashover strength and the severity of contamination, as measured by the per cent salt in the contaminant.

2. Determine the effect of numbers of insulators and total creep distance on flashover strength, to permit extrapolation to 500 kv of the 132 kv and 230 kv operating experience.

3. Determine the relative strength for 60 cycle and switching surge voltages.

4. Determine the relative strengths of vertical and V-strings.

Contamination and Test Procedure

The laboratory tests were designed to simulate as closely as possible the field conditions which produced flashover. For this reason, Locke 5" x 10" insulators with a 12" creepage path were used throughout the investigation. In addition, one test was performed on Ohio Brass 50,000 lb. insulators with a 14.5" creep path.

Since the field observations indicated that the surging phenomenon required several hours to develop into flashover, and since pure salt contamination could not endure for this time period (See Fig. 1, Curve C) the slow-release cement-salt mixture was used to contaminate all insulators. Each insulator was dipped in a slurry made up of 2 parts of cement to 5 parts of water by weight, with 10% salt added, after which the insulator was dried in a warm air atmosphere. In order to lengthen the time that the contaminant would last when testing in a fog atmosphere, each insulator received 3 coats of contaminant in this manner.

The low voltage resistance of the contaminated insulators, as measured in a fog atmosphere, was in the range of 100 to 300 kilo-ohms after about 10 minutes from start of the fog, and remained in this range for several hours, thus duplicating as closely as possible the S.E.C.V. natural contamination. (Fig. 1, Curve A).

The insulators were tested suspended in a fog-filled polyethylene tent 20 feet in diameter and 45 feet high as shown in the drawing, Fig. 4, and photo, Figure 5. A fog was injected in the tent through six nozzles equally spaced around

the top circumference, and a high speed fan on the floor kept the fog in suspension and increased the wetting action under the insulator skirts. Voltage was applied to the bottom of the insulator string, and the top was isolated from the grounded supporting cable by three clean insulators. A resistance shunt was connected across the clean insulators to ground, and the leakage current was monitored by measuring the voltage drop across this shunt. This voltage was fed into a log adapter and amplifier, and then recorded by use of a magnetic oscillograph (Visicorder). It was monitored visually on a cathode ray oscilloscope. In addition to the leakage current, the applied voltage was recorded on the magnetic oscillograph by use of a capacitance divider.

Most of the testing was performed with voltage supplied from a 1000 kva 350 kv transformer fed from a 5000 kva 2300 volt generator. The general test method was to apply the voltage at a level that was close to the estimated flashover strength and hold for about fifteen minutes observing the leakage current. This afforded ample time for the insulators to get thoroughly wet. If no flashovers occurred or appeared imminent, the voltage was increased by five percent and held for one to five minutes depending upon the activity observed. This procedure was repeated until a flashover level was established. Alternate methods tried were:

1, to apply voltage at a level where flashover was reasonably certain and decrease in levels until a withstand was obtained; and 2, apply the initial voltage at a definite withstand level until wet, and then increase at the rate of three kv per minute until flashover occurred. All of these methods had some faults, but method (1) seemed to give the best results in that the minimum flashover level was definitely reached before appreciable contaminant was washed from the insulators.

Switching surge tests were run on several strings of insulators after the 60 cycle flashover level had been determined. For these tests five 140 x 3300 microsecond positive polarity waves were applied at a voltage level, and the voltage changed in about five percent levels until the minimum flashover and maximum withstand levels were determined. Complete critical flashover tests could not be run because of the short time available before contaminant washed off the insulators. In all cases, these switching surge tests were made several minutes after completion of the power frequency tests. Although scheduled originally, time did not permit development of a test procedure to apply switching surges during critical surging at power frequency. Therefore, all switching surge data reported represents only the response of line insulation to a surge developed by energizing a dead line, and not to the case where bus transients may produce multiple line flashovers during critical surging.

In all, a total of 75 60 cycle test runs were made, with strings of 5, 15, 30, and 39 insulators, voltages from 33 kv to 240 kv, and various contamination severity levels.

Surging Phenomena

Adjustment of fog, voltage, and contaminant levels produced essentially the same surging phenomena and leakage currents as observed in the field. Figure 6 is a typical record of insulator current, indicating base periods of several milliamperes with no arc activity, interspersed with periods of high current enduring for a second or two and accompanied by arcs on the underside of the insulators. With the proper voltage adjustment, this activity would terminate in flashover.

In addition, high speed current oscillograms duplicated in all major respects the oscillograms of the field operation (Figure 3), providing further proof that the laboratory operation was quite similar to the line operation.

Concise analysis of the surge current records was difficult due to the wide variation in surge timing and magnitude. However, a statistical analysis was made of a number of the Visicorder test records, by dividing the total test period into a number of intervals, and counting the number of cycles of current surges per minute above various threshold levels in each test interval.

Figure 7 shows the results of such ananalysis for a test of 15 vertical insulators with 0.2% salt contamination. 80 kv was held for 15 minutes, followed by a ramp voltage of 2.5 kv per minute. Flashover developed from a 1000 ma surge at 31 minutes, at a voltage of 117.5 kv, or 7.85 kv per insulator. Note that surge magnitude was 20 ma or less during the initial 3-5 minutes of the test, but that frequencies extended to 150 surges per minute. As the test progressed, currents increased to 300-600 ma, and frequencies decreased to about 30 surges per minute.

Figure 8 shows a similar analysis for a 15 unit V-string, with the same contamination and voltage conditions. Flashover occurred shortly after the 29th minute at 117.5 kv. Note that the surge magnitude early in the test was high relative to the vertical string. This phenomena was evident throughout the tests, possibly indicating a somewhat different mechanism for the V-string surging.

Figure 9 shows the surging data for 15 vertical insulators with 0.8% salt. In this test, the voltage was held at 132 kv and flashover occurred at 16 minutes, developing from one of the 250 ma surges.

Effect of Contaminant Severity

As mentioned earlier, tests were run on strings of insulators contaminated with various levels of salt in the contaminant. A large spread of 60 cycle flashover results was obtained, which is usually the case when testing contaminated insulators. These data are shown in Figure 10 where inches of creep distance per kv are plotted against percent salt in the contaminating slurry. This curve might be considered pessimistic in that it goes through the highest points rather than the average level of all tests. It was obvious during the test, however, that these worst conditions were a reality that could be repeated, and therefore should be considered when designing a trouble-free line.

Figure 11 is a semi-log replot of these minimum flashover data, including a calculated concentration of salt for an approximate comparison of measured natural contamination with the laboratory artificial contamination. Also shown on this curve are the minimum flashover levels per insulator at 0.2, 1.0, and 5% salt solution, obtained by dividing the 12" creep per insulator by the specific creep values of the curve.

Figure 12 shows the switching surge withstand test results in terms of specific creep versus contamination severity. Shape of this curve is similar to that of the 60 cycle curve.

The low impedance of the contamination, particularly above 2% salt solution, caused severe regulation of the switching surge tail, such that actual flashovers did not occur in some cases, making the results somewhat difficult to interpret. However, in many cases, the total voltage would regulate suddenly to 30% of normal level, such that the surge crest voltage could be considered a flashover level.

Note that the severe contamination reduced the 60 cycle flashover per insulator from a clean wet catalog value of 50 kv to a range of 6 to 9 kv. However, it appears that moderate contamination, below 2% salt, actually increases the switching surge withstand over the clean wet value, and the very heavy contamination, at 10% salt, causes only a 20% reduction. The insulator switching surge withstand values shown in Figure 12 should be compared with the approximate value of 50 kv clean wet withstand indicated by most of the recent full scale 500 kv tower tests (with the window size permitting all insulator flashovers).

Effect of Number of Insulators On String Flashover Level

The tests indicated that for a given contaminant level there is a linear relation between flashover strength and number of insulators. In one test series where an 0.8% salt solution was used, the flashover strength for five insulators averaged 47 kv and that for fifteen insulators averaged 144 kv, or 9.4 and 9.6 kv per insulator respectively. In another test series using a 2% salt solution, values of 122 kv for fifteen insulators and 294 for 39 insulators were obtained. This represents 8.1 and 7.5 kv per insulator respectively. Considering the spread of results usually obtained in contamination testing, this is considered very good agreement. These and other data are shown in Figure 13.

Effect of Creepage Length

To determine the effect of total creep distance, a string of 15 Ohio Brass 50,000 lb. insulators was tested. Since these insulators are 11-1/2" diameter with a small additional skirt, their creep distance is 14.5" as compared with the 12" creep of the insulators used for the other tests. However, since the shape of the two insulators tested is quite similar, the following test data does not apply to the various fog-type insulator designs now used to obtain extra creep.

The data obtained for these tests are shown in Table IV. It can be seen that for 60 cycle voltage the inches per kv are identical for the two types of insulators, but that the high creep insulators were appreciably stronger for switching surge voltages. Only one switching surge test was made, and therefore in the light of the previous spread of results that have been obtained, the superior switching surge performance of the high creep insulators should not be relied on. The significant fact is that both the 60 cycle and switching surge strengths were increased

by the use of high creep insulators to at least the same degree as the creepage length was increased. The switching surge data throughout the investigation was quite erratic and hard to interpret, but the sixty-cycle was under good control for those phases reported herein. From these data it can be concluded that the strength of contaminated insulators is proportional to their creepage lengths for 60 cycle voltages and may increase at a greater rate than the creepage distance for switching surge voltages.

Vee Strings Versus Vertical Strings

A comparison of the strengths of vertical and V-strings was made with strings of 15 insulators for two contamination conditions: 0.8% salt and 2.0% salt. Only one leg of the V-strings was contaminated in order to simplify the leakage current measuring problem.

The data for these tests are given in Table V. For both 0.8% and 2% salt the lowest V-string flashover was ten percent below that of the lowest vertical string flashover. Considering the spread of results that occurred for identical conditions throughout the test program, this is not conclusive evidence that V-strings are weaker than vertical strings. It does make quite certain, however, that for identical laboratory test conditions V-strings are no stronger than vertical strings. This is contrary to actual field experience where it has been observed that V-strings are apt to have higher current surges than vertical strings at the onset of a fog, but no flashovers occur; whereas the vertical strings are slower to develop surging, but once started, they often cascade into a flashover. The initial high current surging noted in field installations on the V-strings was duplicated in the laboratory testing and was attributed to the accumulation of contamination on the lower side due to fog condensation and run off. The fact that in the laboratory tests, flashover for V-strings developed at somewhat lower voltages than for vertical strings, whereas in the field the opposite has been observed, might be attributed to the manner in which contamination accumulates on the insulators in the field. The laboratory dipping method resulted in a fairly even distribution of contaminant.

PITTSFIELD MOTION PICTURE TESTS

During the course of the Pittsfield Laboratory tests, it became clear that a better understanding of the surging and flashover mechanism was required, to explain the orientation effect observed in the field, the shape of the contamination severity curves, the linearity of flashover with creep length, and the arc activity during the many periods of critical surging observed in the field and laboratory.

Therefore a test program was initiated with the primary purpose of establishing a firm description of the flashover phenomena as well as the build up and decay of the surging process when flashover does not occur. It was decided that a high speed movie using approximately 1000 frames per second would be most useful in evaluating the various phenomena and in particular it was desired to obtain a comparison of the vertical and V-string configurations utilized throughout the test program as well as some information on a horizontal string which was not obtained during the more extensive test program.

Test Procedure

The high-speed movie tests used a small fog tent similar to the larger tents used in the previous tests. High speed-movies were taken on tests of

Five Vertical String Insulators
Three Horizontal String Insulators
Three 45 degree (Vee) String Insulators

Two high speed cameras were used in each test. For the vertical string the cameras were oriented such that one would be photographing primarily the under side of the insulators while the other would be photographing primarily the top surface of the insulator. In the horizontal and V-string setup the two cameras were again oriented such that one would be photographing the skirted side of the insulator while the other would be photographing the upper side of the insulator.

Fastex cameras were used for these tests. The camera speeds could be adjusted from approximately 500 frames per second to 3000 frames per second but the speed could not be adjusted precisely prior to any test. Therefore a series of test runs were made to determine the optimum frame speed. The most pertinent results were obtained using the initially proposed 1000 frames per second.

Triggering of the cameras posed some difficult problems. The primary purpose of the program was to evaluate both the build up and the decay of surging as well as the build up subsequent to flashover. A threshold-level triggering circuit was developed which would trigger the cameras at any desired current crest. The threshold-level current monitoring device performed satisfactorily but the delay in camera start following trip signal as well as the substantial time required for the cameras to reach full speed resulted in failure of this approach to the problem. A less sophisticated approach which did have a few shortcomings was developed such that movies of the flashover phenomena could be obtained during the planned test program, as follows:

1. Following triggering of the cameras by a low leakage current surge the source voltage was manually raised to a level which would assure flashover. The delay between the automatic triggering of the cameras by the threshold device and the ability to manually raise the voltage to a level which produced flashover was sufficient to allow the cameras to reach operating speed prior to flashover.

2. The cameras were manually tripped and the source voltage was raised to produce flashover. Again a natural lag in the manual increase voltage produced sufficient delay to allow the cameras to reach operating speed.

Test Results

Performance of the vertical, horizontal, and V-strings will be discussed separately. However, one factor common to all three configurations was a light blue corona glow around the pins of all insulators during the 3 ma base current periods.

The vertical string of five insulators was tested with 2% salt contamination. At this severity 30 to 40 kv, or 6 to 8 kv per insulator, was required to start satisfactory critical surging.

The transition from base current to critical surging occurred within a few cycles. Single arcs extending from the pins toward the outside edge of the undersurface appeared and developed in intensity on all five insulators. The arc paths were maintained through voltage zeros, although of course the light intensity varied directly with the applied voltage. Radial position of the arcs was usually different between insulators and appeared to vary at random. Also, in some cases the arcs extended from the third skirt to the outside edge as the voltage approached maximum and then retracted to the initial position as the voltage increased. The top camera film indicated no arc activity on the top insulator surfaces during critical surging. Therefore, the entire string voltage less underside arc drops, was equally divided among the five top insulator surfaces, causing a high level of string current but without flashover.

Reproduction permitting, underside arcs can be seen on all thirteen of the insulators visible in Figure 5, which was taken during a surging period.

Several 5-15 cycle surging periods which did not develop into flashover were photographed. All arc activity ceased at the end of these periods and the string current decreased from several hundred milliamperes to the base level.

On a number of tests, the manual increase in voltage forced flashovers to develop from surging. Just prior to flashover, all underside arcs were fully extended to the outer edges of the insulators, and in some cases streamers were seen moving around the edge toward the top surface. The flashover was initiated on one of the insulators by an extension of the arc across the top surface to the cap. This extension occurred between two frames, i.e., in less than a millisecond. During the next few cycles, the remaining four insulators, flashed over in the same manner, completing the flashover circuit.

During the 15-20 cycle period following flashover, the ends of the top arcs remained at the outside circumference and at the initial contact point of the cap, while the center portion of the arc moved upward by convection. This movement resulted in consolidation of the five separate insulator arcs into a single arc which then moved away from the string.

A number of tests were made on three horizontal insulators contaminated with 2% salt. 30 to 35 kv, or 10 to 12 kv per insulator was required to produce vigorous surging. Although in general, these surging voltages were approximately 50% higher than those required for the vertical strings, the conclusion that these tests proved the orientation effect observed in the field is not justified, because the quantity of voltage measurements was much too small to be statistically valid. It is interesting to note, however, that the 220 kv horizontal strings in the field have never flashed over while operating at approximately 8.5 kv per insulator.

As on the vertical strings, the surging arcs were initiated at the insulator pins and extended to the outside edge prior to flashover. However, instead of the random variation in radial arc position on the vertical strings, the horizontal arcs tended to rotate to a position above the pin, probably due to thermal convection.

The film also indicated that the surge-to-flashover transition mechanism of the horizontal string was quite different from that of the vertical strings. As the skirt side arcs reached the upper edge of the insulator, they did not immediately flash over to the caps, but instead extended into the air for several inches and then looped back to terminate on the top surface of the insulator at various points. In some cases these long arcs would withdraw to their initial position for a few cycles and then develop into another arc terminating on the top surface. With sufficient voltage the arcs eventually terminated on the caps completing the flashover circuit.

3 unit V-strings were tested with both 2% and 8% salt. As on the horizontal strings, the critical surging voltage was somewhat higher than that required for the vertical strings, but the small record quantity precludes a valid statement on the orientation effect. Generally, the critical surging and transition mechanism was similar to that of the horizontal string for 2% salt.

However, new arc effects appeared on the 8% salt tests. Early in the surging operation separate arcs appeared at various locations on the skirt side, many of them between two skirts. As the voltage forced flashover, these arcs consolidated into two separate arcs extending in different radial directions from the pin to the outside edge. Although these two arcs were absorbing much heavier leakage current from the top surface as they extended to the outside edge, their lengths were no greater than the single arcs seen at lower salt concentrations, and therefore, the insulators were no closer to flashover at any particular stage of the operation. This mechanism constitutes one possible explanation for the shape of the flashover curve shown in Figure 10. In addition, surge arcs were seen originating from the insulator caps across the top surfaces.

ANALYSIS AND DISCUSSION OF RESULTS

For many years, transmission engineers have observed the surging mechanism described in this paper, and have recognized the primary role of this mechanism in producing transmission line flashovers (Ref. 1, 2, 3). Indeed, measurement of the quantity and magnitude of the surges has been an important part of the test procedure at many insulator test stations, such as the stations at Ohio Brass, at Croydon and Brighton in England, at Mons in Belgium, and at Recklinghausen in Germany (Ref. 4, 5, 6).

However, a few of the details of the surge wave shape and mechanism observed during these tests have never been published, to the authors' knowledge, justifying additional discussion of this mechanism and of the other results reported in this paper.

Mechanism of Flashover

The analysis of the growth of an arc from the pin across the ribs on the underside of a polluted insulator to the cap can only be qualitative, because the complex shape of the insulator and the number of variables involved make any mathematical calculation a formidable task. Such factors as the rates of wetting of the pollution due to the fog, the time elements entailed in the drying out of bands under the influence of leakage current, string orientation, wind velocity and the like, and the random nature of step voltages which can occur when a multi-disc string is considered, all inhibit the derivation of formulae to evaluate the probable performance of insulator strings in service. The theories propounded by E. Nasser (Ref. 7) go a long way towards describing the mechanism of an arc on a plain cylinder, but require further development to explain the process entailed when a whole string of insulators is involved. An attempt has been made to set down a qualitative explanation of the phenomena which lead to the flashover of strings of polluted cap and pin disc insulators.

1. From swab tests taken on service insulators, it has been found that the amount of pollution is three times heavier on the underside of the disc then on the upper surface, and if it is assumed that the pollution is evenly distributed on each of the surfaces, then it can be said that the resistance per unit area is at least three times higher on the top side than on the underside of the disc. By dividing the 11" creepage path into 28 bands of 1 cm. width and taking the resistances of the bands to be proportional to the reciprocals of their mean diameters, we can plot a curve of the resistance of each successive band. The "Fully Wet" Curve Figure 14 is such a curve for a polluted disc removed from service and is formed by plotting the resistance of the successive bands when the insulator is fully wetted and is carrying no leakage current. It will be noted that the resistance is far from uniform across the disc, and in fact is comparatively highly concentrated in the vicinity of both the cap and the pin.

2. As damping due to the fog commences, the resistance reduces in line with the I.R. - time curve of Figure 1 and leakage current starts to rise, as has been shown on the chart records. This gives rise to concentrated local heating in the vicinity of the cap and pin, which tends to dry out the pollution in those zones, in turn increasing the resistance and limiting the increase in leakage current.

3. Away from the cap and pin, the resistance continues to fall, and this further distorts the distribution of resistance across the disc as is shown by the progressive curves in Figure 14.

4. The voltage distribution across the disc is considerably distorted in line with the resistance distribution (see Figure 15), and because of the higher electrical stress in the vicinity of the small diameter pin, a glow discharge commences and ultimately an arc is struck across the dry band on the underside of the disc. The electrical stress is lower in the vicinity of the cap, and this phenomenon does not occur there, although the voltage gradient is high and dry banding is proceeding.

5. When the arc is struck, there is a sharp rise in leakage current, as evidenced by surging on the chart record, but in the early stages the arc length is limited by the ballast resistances of the main body of the disc and the dry band at the cap. Initially, the arc strikes to the first rib on the underside of the disc.

6. The arc root is centred on the first rib, and if it is not to extinguish, then it must maintain its current in one of two ways, as the area around the arc root dries out: -

   (a) Move to one edge of the dry band and rotate around the rib with the dry band following it.

   (b) Remain approximately centred in the dry band feeding on the edges as the band increases in area by a number of filamentary arcs which flow from the arc products and ionised air which are being released by the arc and which are trapped in this location.

   Probably there are elements of both of these in the actual behavior, but by and large the arc tends to remain rooted in one position.

7. The sharp rise in leakage current generates appreciable heat in the vicinity of the cap and this results in an increase in the ballast resistance at this point. This has the effect of reducing the arc current and reducing the arc voltage to the point where the arc goes out. This explains the short duration of those critical surging periods not terminating in flashover.

8. After arc extinction, the process restarts with wetting down of the pollution and distortion of voltage across the insulator until a fresh arc is started again.

9. If the fog persists, the total resistance of the insulator reduces, and the arc can strike with more current and over a longer length. The ballast resistance of the main body of the disc becomes less effective, and the control is now being exerted mainly by the dry band in the vicinity of the cap. The surging becomes more violent and the stage can be reached where there is insufficient time for increase in ballast resistance at the cap to prevent extension of the arc to the rim of the disc and ultimately to flashover.

10. Two further factors may now have an effect upon the behavior of the arc. Firstly, there may be step changes of voltage and current applied in one insulator by sudden arcs being struck on other insulators, if the whole process is not synchronized on all insulators simultaneously, and this may result in lengthening of the arc or cascade development where arcs are about to be struck across dry bands. Secondly, the performance of

long arcs may be modified by low resistance shunt paths, which exist in those portions of the insulator not bridged by the arc, which will tend to inhibit the growth of arc length - this factor being of more significance where the string is tilted and thus moisture tends to be unevenly distributed over theinsulator area.

11. When the arc reaches the rim of the insulator, its further propagation is influenced by the orientation of the string, since in suspension strings it is possible for the arc to rise with the ionised gases and to enter the arc on the underside of the insulator immediately above it. This will give rise to very rapid flashover since all control of the arc has been removed by the shorting out of the ballast resistances.

12. The superior performance of V-strings and strain strings is believed to be due to three primary factors -

(a) The better cooling by convection which improves the differential rate of dry banding at the cap and at the pin, thereby permitting the ballast resistance at the cap to exercise more control.

(b) A higher conductivity shunt path across the arc due to moisture flowing down the tilted insulators.

(c) The better dispersion of ionised gases, due to convection air currents moving these gases away from the insulator string. Note that this same effect may also account for the cessation of surging on vertical strings when the wind velocity increases to above 5 mph.

Line Design

The saturation shape of the flashover-contamination curves of Figures 10 & 11 gives promise that lines with cap and pin insulators can be designed to operate successfully in highly contaminated areas, since it appears unnecessary to increase insulation linearly with the amount of contamination. For instance, a line with 10% margin above the 1.7 inches/kv specific creep at 2% salt contamination could withstand without flashover a very substantial increase in contamination such as might occur during salt fogs or other sources of temporary contamination.

On the other hand, lines operating below the knee of the curves, say at 1.3 inches/kv, as on the S.E.C.V. 220 kv lines, would flashover with short-term increases in pollution level, in spite of frequent live-line washings.

Furthermore, it appears that high creep insulators with standard cross-section, such as the 17" and 18" designs now available, can be used to obtain the required level, at some saving in string length and tower steel. However, the use of this design philosophy with other insulator shapes, such as the various fog-type designs, is not warranted pending further field and laboratory experience, since the high speed movies and the authors' theoretical studies clearly indicate the importance of insulator shape to the critical surging mechanism.

Therefore, a reasonable 500 kv line design to operate in heavily contaminated areas might have 1.8 inches/kv specific creep, or 540 inches total creep at 300 kv L-G, this creep distance provided by 32 insulators with 17" creep. This design assumes vertical strings.

In spite of the negative results obtained on the few V-string tests of the Pittsfield investigation, the weight of the evidence at this time indicates that this insulation level would perform better in vee configuration, as follows:

1. Superior performance of horizontal strings in the field and the cessation of critical surging on vertical strings with wind velocity above 5 mph.

2. The difference in surge-to-flashover transition mechanism, as observed on the high speed films.

3. Theoretical studies presented in the previous section.

High Speed Movies

The wealth of information on the critical surging mechanism provided by the high speed movies was so great that detailed analysis is still in progress and cannot be presented in this paper. This method of test together with good recording of string current and voltages, is commended to other researchers in this field.

Typical of the data provided by these tests is the following observation. As moderate surging develops toward severe surging, the arc reignition point, (See Fig. 3B) decreases from about 70° after zero to about 30°. As the arc reaches the point of no return, the ignition advance takes place in steps, and the ignition point gradually decreases to about 20° to 5°. Once the power follow arc commences, the ignition point is at current zero and the wave form is approximately sinusoidal.

The surging and flashover mechanism observed during these tests did not conform to current theory (Ref. 1) which postulates that the instability caused by dry banding produces complete flashover of one or more insulators in the string, with arc inactivity on the other insulators.

For instance, the transition from base to surge current and resultant undersurface arc activity occurred within a few cycles on all insulators in the string. This might be expected from the results of a recently completed digital computer analysis of voltage grading on contaminated insulators (Ref. 8). In the terminology of the reference paper, q of the insulators with this amount of contamination is approximately 400, with an X_C per insulator of 80 megohms, and an R per insulator of 0.2 megohm (See Fig. 1). With this value of q, all computer solutions presented in Ref. 8 indicate essentially linear voltage and power grading, even considering all possible capacitance fields.

During the critical surging operation, there were a few variations in arc length and position between insulators, as noted above. However, as the operation approached the surge-to-flashover transition point, all insulators in the string were

arcing in the same manner and parallel in time, at least within the millisecond time resolution permitted by the test procedure. Therefore, the linearity of string flashover with number of insulators shown in Fig. 13 could be expected, because all insulators share equally in the transition to flashover.

CONCLUSIONS

1. The critical surging mechanism observed in the field and laboratory appears to be the prime factor in producing power frequency flashovers, with the S.E.C.V. type of contamination, and possibly with most or all other types of contamination.

2. The severe contamination studied reduces insulator power frequency flashover level from the 50 kv clean wet value to a range of 6 to 9 kv per insulator.

3. Shape of the flashover-contamination severity curves indicates that an insulation level, necessarily high, can be chosen which will operate satisfactorily in the most severe contamination areas.

4. It appears that the moderate contaminations tested increase the switching surge withstand above the clean wet value, while the most severe contamination reduces these values to approximately 20% below the clean level.

5. For the standard cap and pin insulator shapes tested, string flashover is linear with number of insulators from 5 to 39, at the same contamination severity.

6. Within the test limits, power frequency flashover is approximately proportional to total creep distance.

7. Although much additional research is required for proof, the weight of the present field and laboratory evidence indicates that horizontal and V-strings have a higher flashover level than vertical strings, because of fundamental differences in the critical surging and flashover mechanisms.

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TABLE I

LATROBE VALLEY POWER STATIONS

	Yallourn						Morwell	Hazelwood
	A	B	C	D	E	Briq. Factory		
Years of Commissioning	1924-1928	1932-1938	1954-1957	1958-1959	1961-1962	1924 1931	1958-1961	1964 Onwards
Capacity MW	75	100	106	100	240	21, plus Process Steam	170, plus Process Steam	600 (late 1966)
Source of Coal	Yallourn O.C.	Yallourn O.C.	Morwell O.C.	Yallourn O.C.	Yallourn O.C.	Yallourn O.C.	Morwell O.C.	Morwell Open Cut
Approximate Normal Daily Coal Consumption, tons	7,500		5,000	6,000	10,000	3,000	3,500	20,000
Dust Collectors Installed on Boilers	None	None	Multi-clone	Multi-clone	Multi-vortex	Some Multi-clones	Centicell	Electro-static Precipitator

TABLE II

COAL ANALYSES

	Yallourn Open Cut *		Morwell Open Cut **	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Moisture Content (% in coal as received)	63.5	70.5	60.6	62.5
Coal Constituents (% in dry coal)				
Ash Content	0.6	2.6	3.1	4.8
Carbon	64.5	67.5	64.8	68.8
Hydrogen	4.50	4.90	4.60	4.90
Sulphur	0.11	0.43	0.51	1.19
Chlorine	0.01	0.11	0.08	0.25
Ash Constituents (% in dry coal)				
SiO_2	0.02	1.00	0.07	0.90
Al_2O_3	0.02	0.94	0.05	0.20
Fo_2O_3	0.18	0.72	0.27	0.68
CaO	0.02	0.20	0.67	0.96
MgO	0.12	0.36	0.63	0.89
Na_2O	0.04	0.10	0.25	0.50

Upper and lower limits include 95% of values of constituents.

* From Specification for Yallourn "W" Power Station.

** Weekly Coal Deliveries to Hazelwood Power Station.

Ash constituents not listed comprise principally sulphate (SO_3) which contributes 20-40% of the ash content, and which is combined with the sodium and part of the calcium contents, and chloride (Cl), potassium oxide (K_2O), titanium oxide (TiO_2) which are present in small amounts.

TABLE III - TYPICAL POLLUTION CONCENTRATIONS ON LINE DISCS

		Disc P9		Disc 56-10	
Distance of line disc from power station		0.5 mile		10 miles	
String arrangement		8 discs vertical		15 discs vertical	
Service voltage		132 kV		220 kV	
Years disc in service		2-1/2		10	
Size of disc		10"x5"x15000 lb.		10"x5"x11000 lb.	
Disc material		glass		porcelain	
Surface creepage distance - inches		11.3		11.6	
Disc maintenance		No washing		Washed each 2nd Yr.	
Date of flashovers		21, 12, 65		2, 3, 65 (Washing due)	
Weather conditions at flashover		Light smog		Severe smog	
		Top	Bottom	Top	Bottom
Conductivity					
Equivalent NaCl on surface	mg	66.0	822.5	14.8	156.0
Equivalent NaCl concentration	mg/cm^2	0.112	1.13	0.024	0.19
Area of polluted surface	cm^2	590	730	610	820
Insolubles					
Water - insoluble pollution	mg/cm^2	0.49	6.9	0.038	2.0

Composition of main constituents of water-soluble pollution
(for disc 56-9 adjacent to disc 56-10 above)

			Representative Values	
			Top	Bottom
Sodium	as Na	%	5.5	1.3
Calcium	as Ca	%	11.0	17.6
Magnesium	as Mg	%	7.2	3.4
Chloride	as Cl	%	11.0	3.1
Sulphate	as SO_4	%	45.2	50.5

TABLE IV

Sixty-Cycle and Switching Surge Strength of Standard and High Creep Insulators with 2% Salt Contamination.

		60 Cycle		Switching Surge	
No. Ins.	Creep inches	F.O. kv-rms	inches/kv	F.O. kv-crest	inches/kv
15	12	118	1.53	710	.253
15	14.5	143	1.52	1180	.184

TABLE V

Comparison of Sixty-Cycle Strengths of Vertical and V-strings.

Lowest Flashover KV - RMS

0.8% Salt		2% Salt	
Vertical	V-string	Vertical	V-string
132	119	122	118
145	119	118	106
Average 139	119	120	112

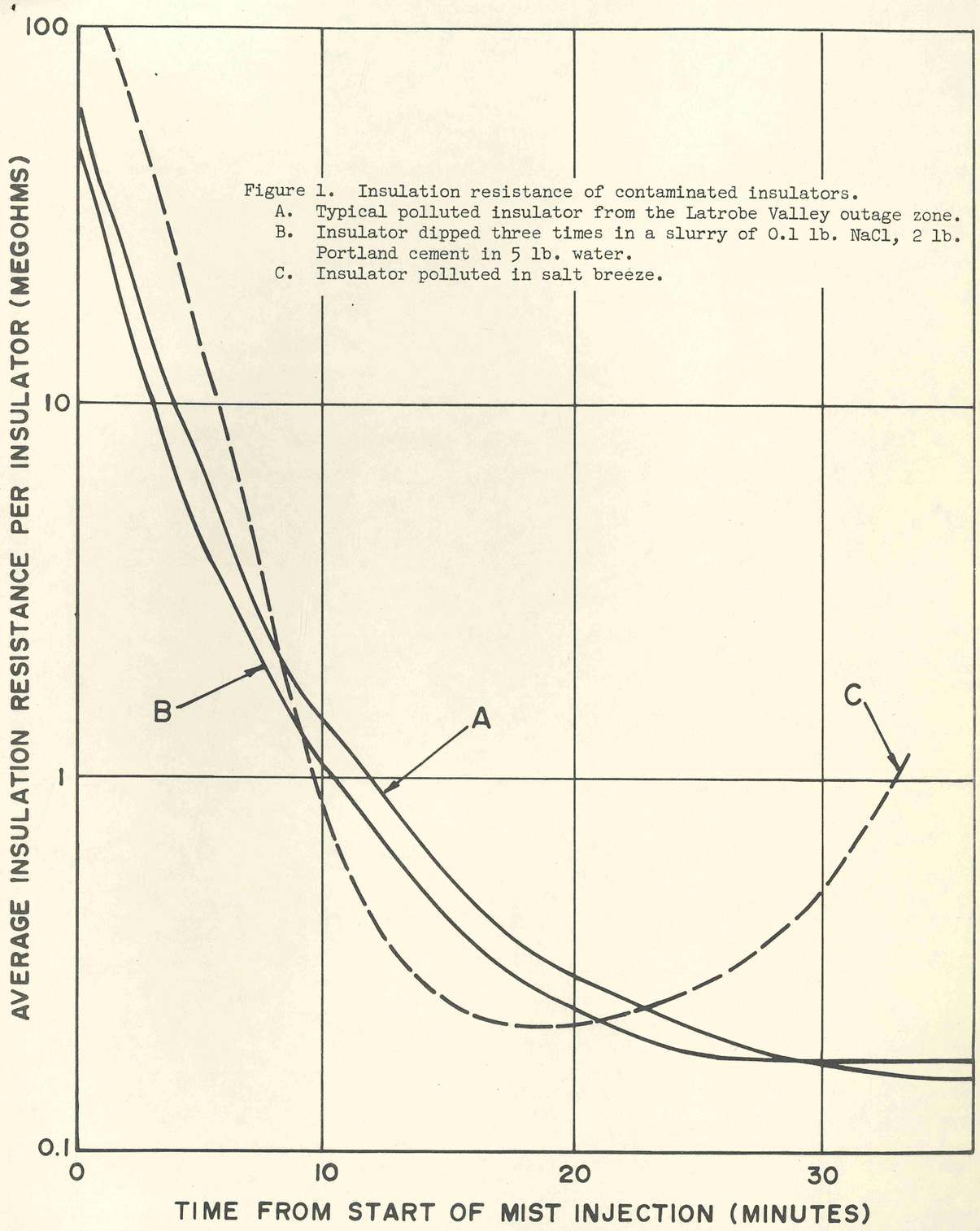


Figure 1. Insulation resistance of contaminated insulators.
A. Typical polluted insulator from the Latrobe Valley outage zone.
B. Insulator dipped three times in a slurry of 0.1 lb. NaCl, 2 lb. Portland cement in 5 lb. water.
C. Insulator polluted in salt breeze.

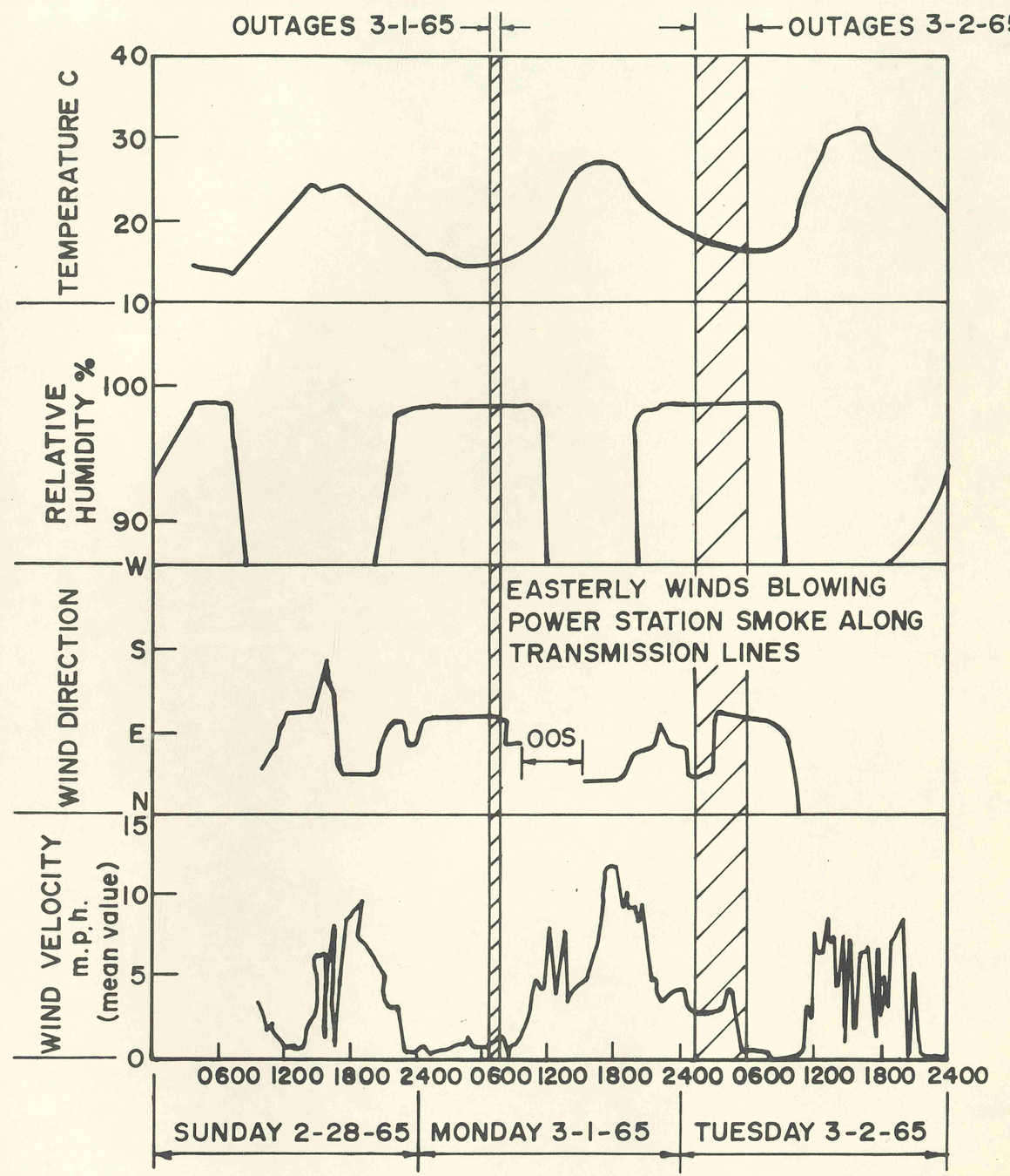
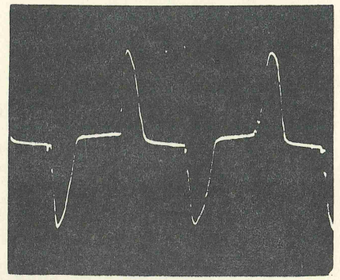
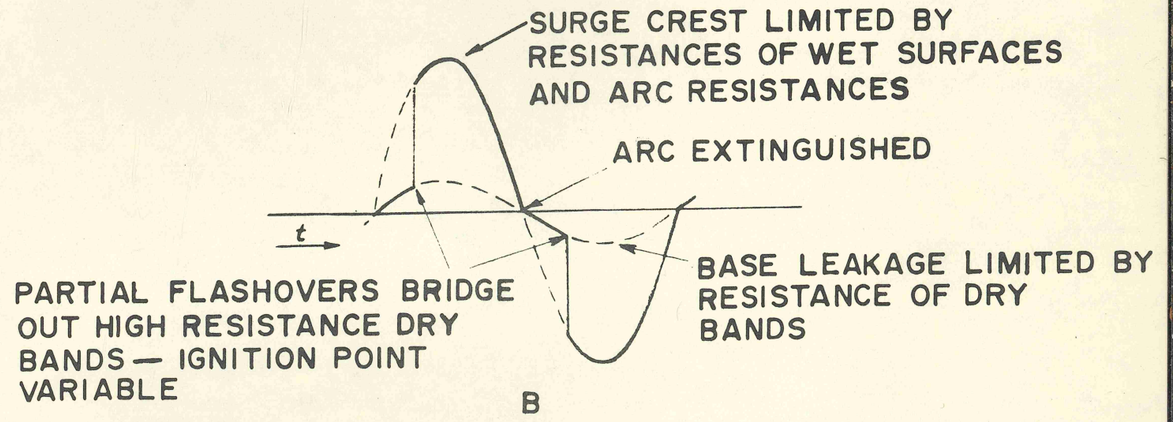


Figure 2. Typical meteorological conditions during outage period.



A



B

Figure 3. Basic wave forms of surge currents.
A. Field oscillogram of minor surging - 15 ma peak.
B. Interpretation of wave form.

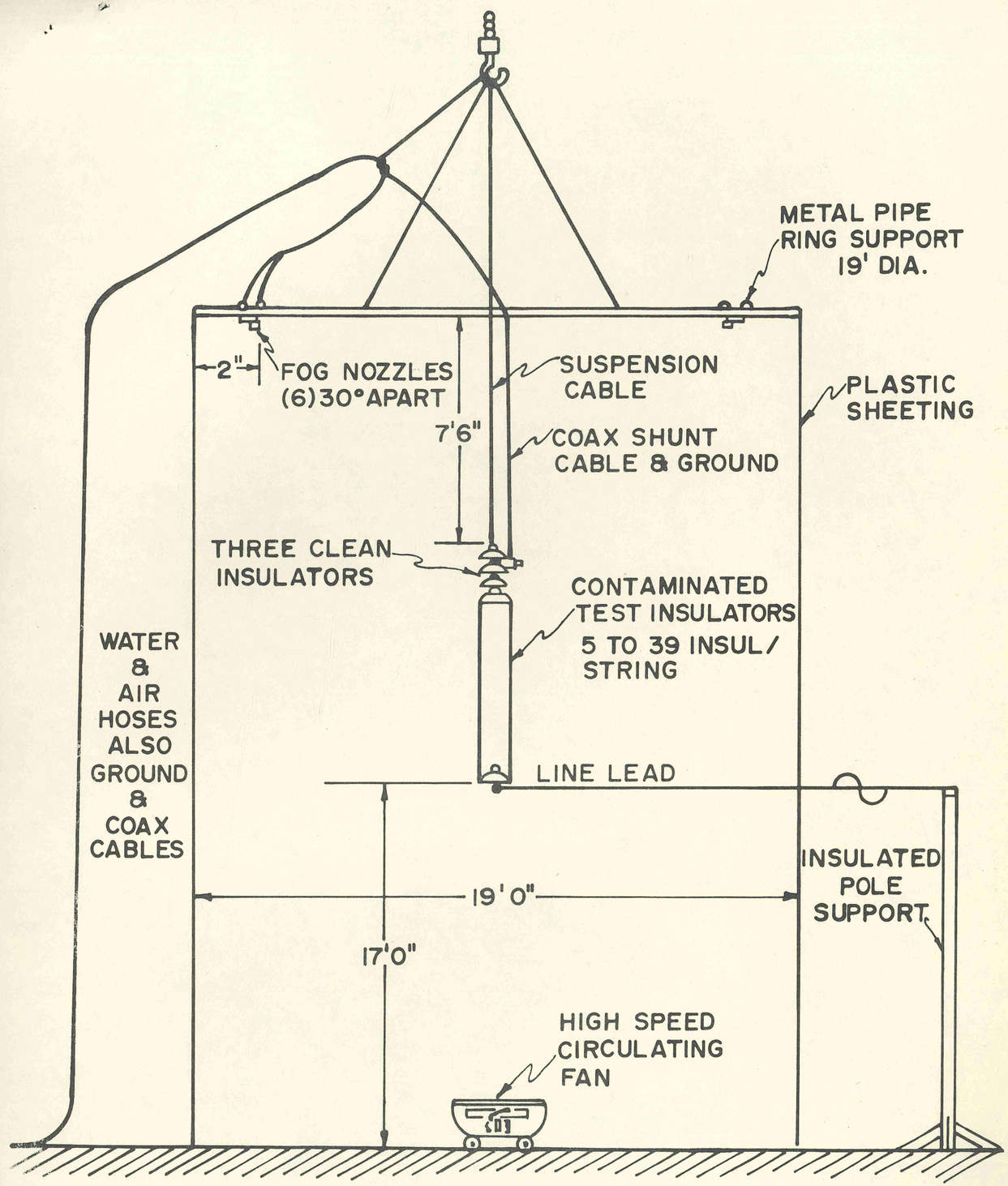


Figure 4. Fog chamber arrangement.

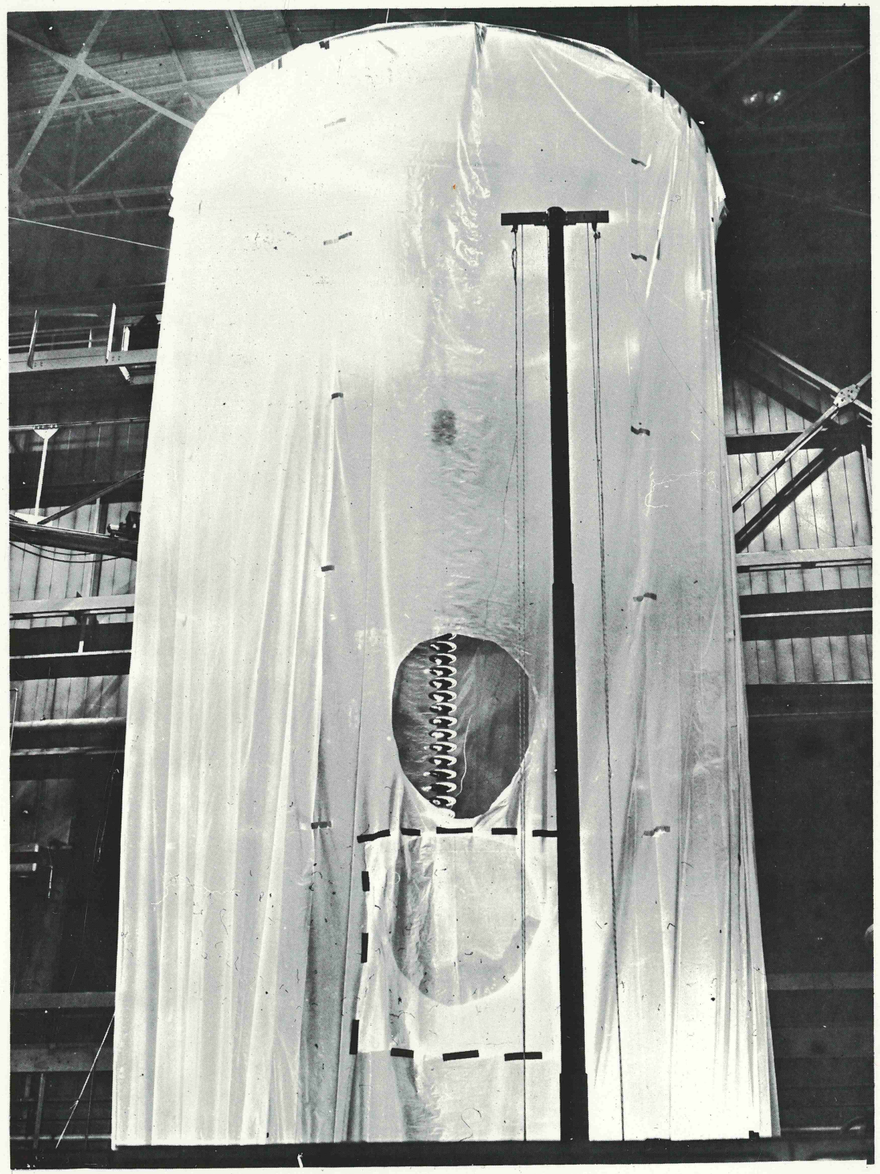


Figure 5. Fog chamber and insulators under test.

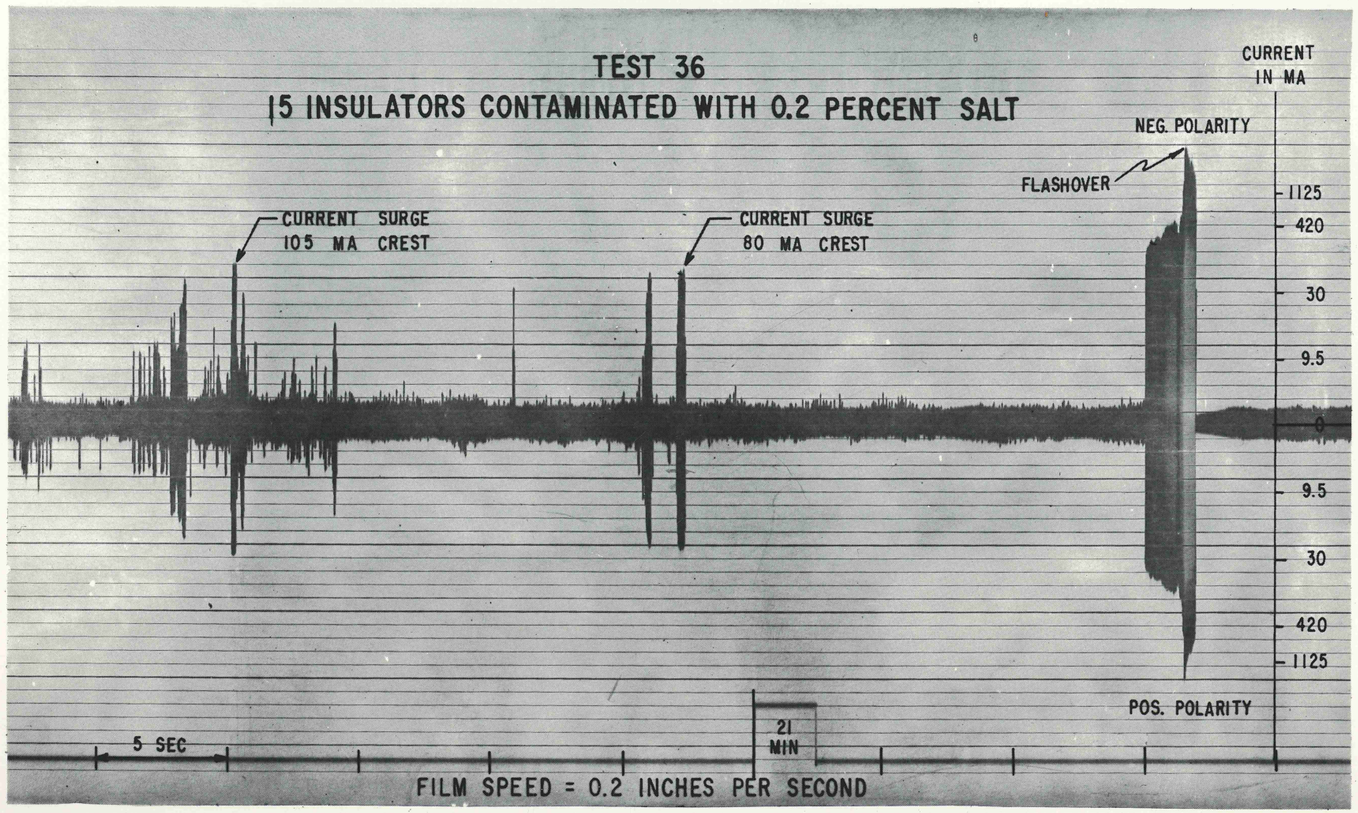


Figure 6. Surge current record - Test 36.

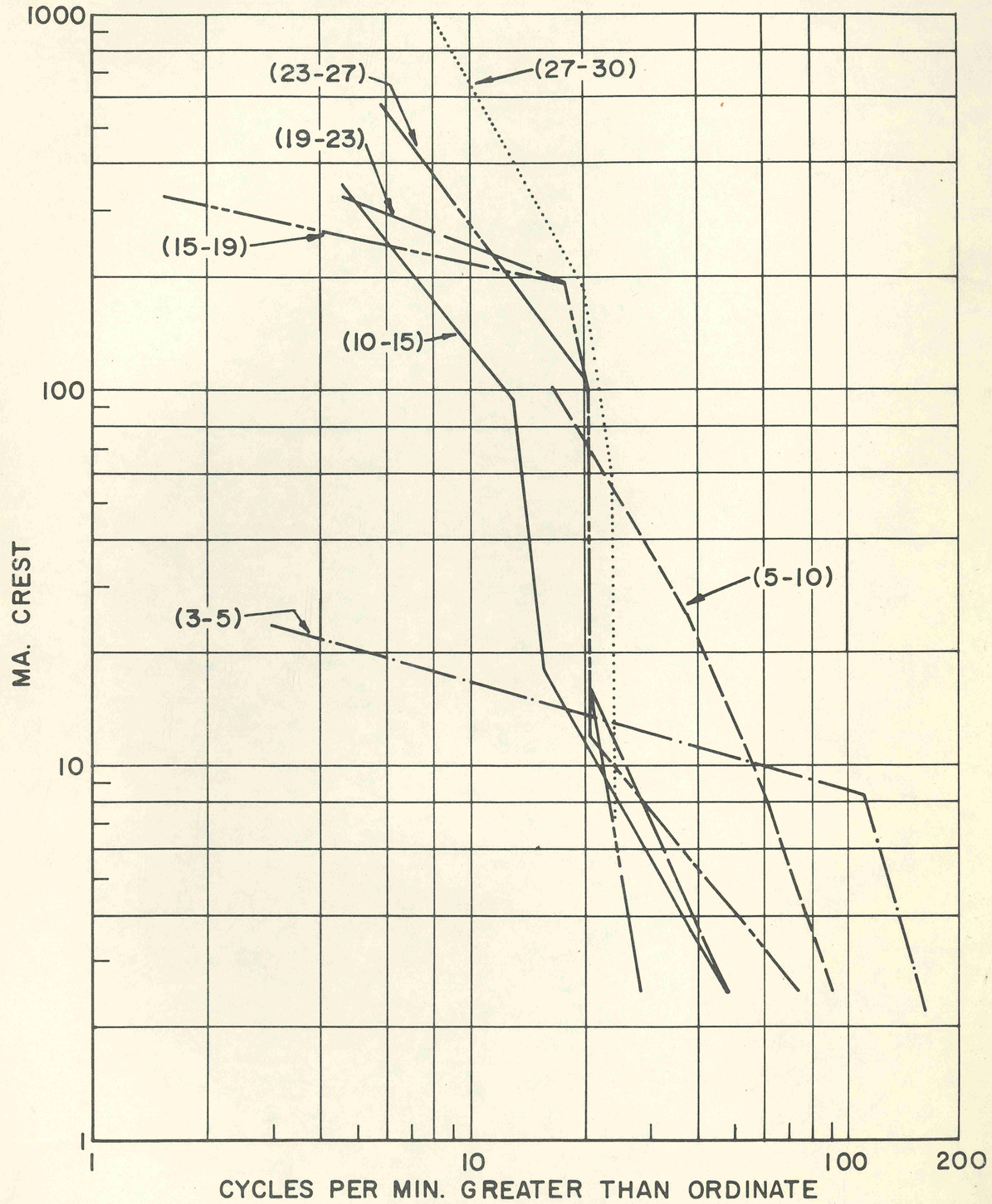


Figure 7. Surge analysis - 15 vertical insulators with 0.2% salt contamination. Curve designations are time period in minutes, measured from start of fog.

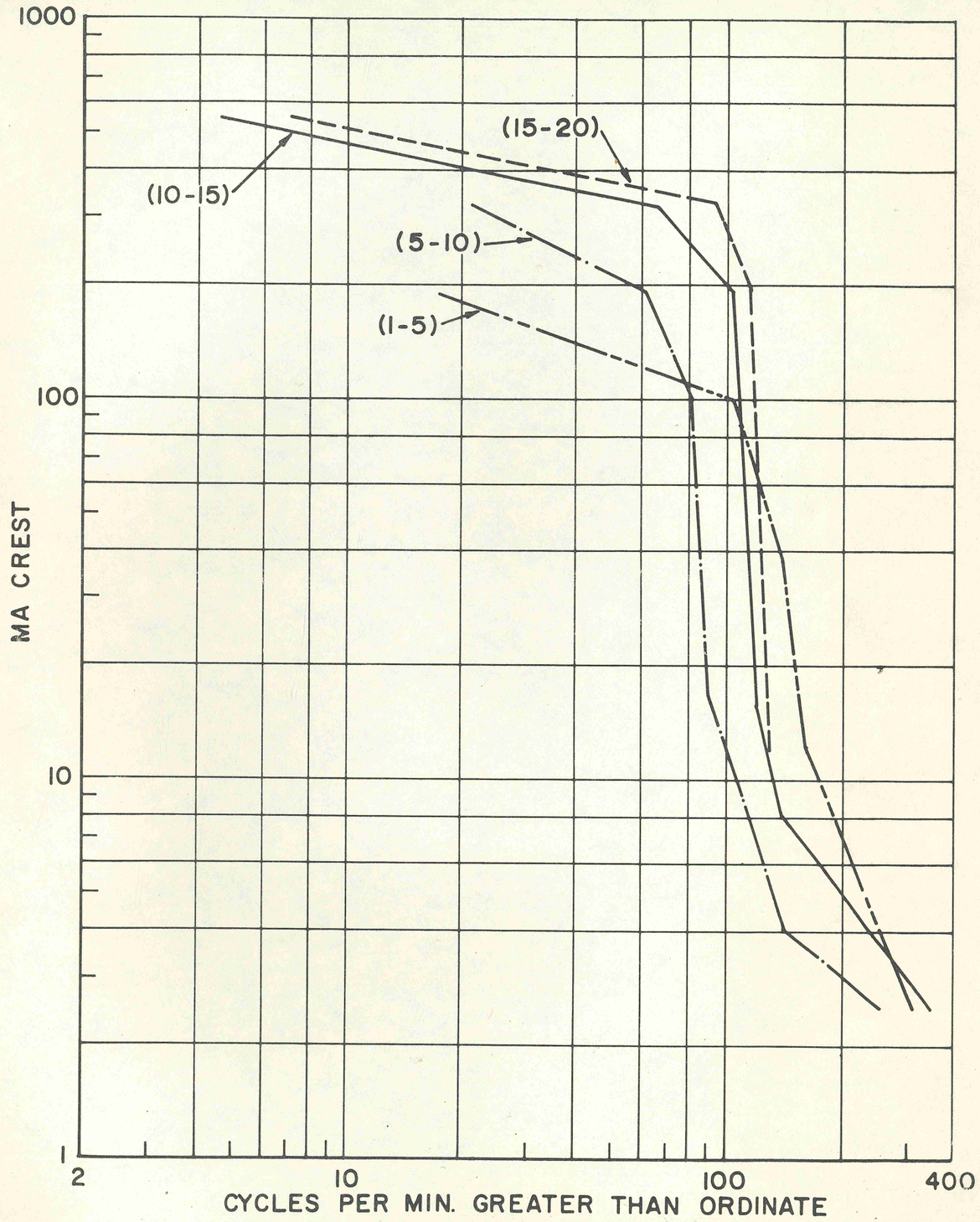


Figure 8. Surge analysis - 15 vee insulators with 0.2% salt contamination. Curve designations are time period in minutes, measured from start of fog.

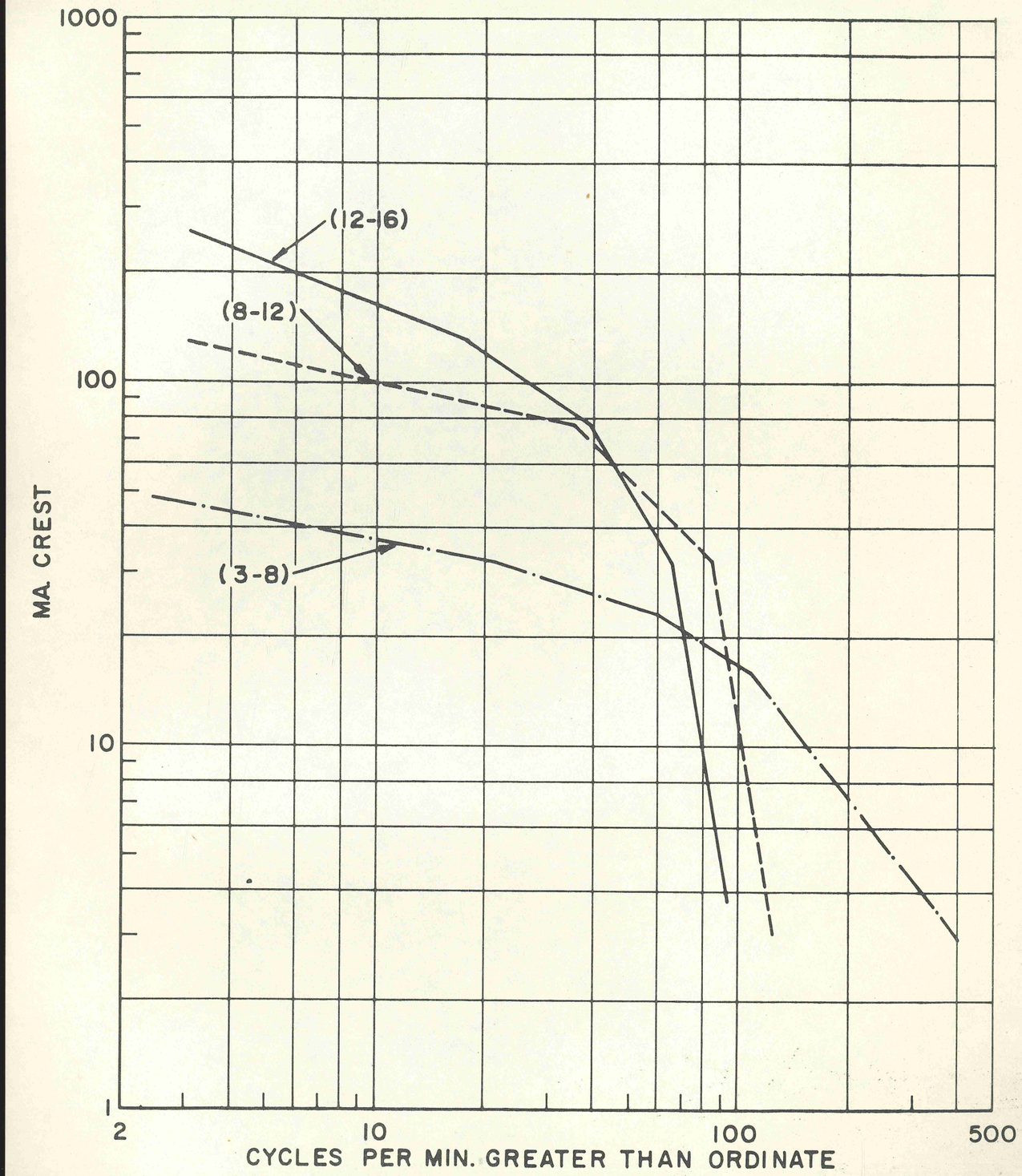


Figure 9. Surge analysis - 15 vertical insulators with 0.8% salt contamination. Curve designations are time period in minutes, measured from start of fog.

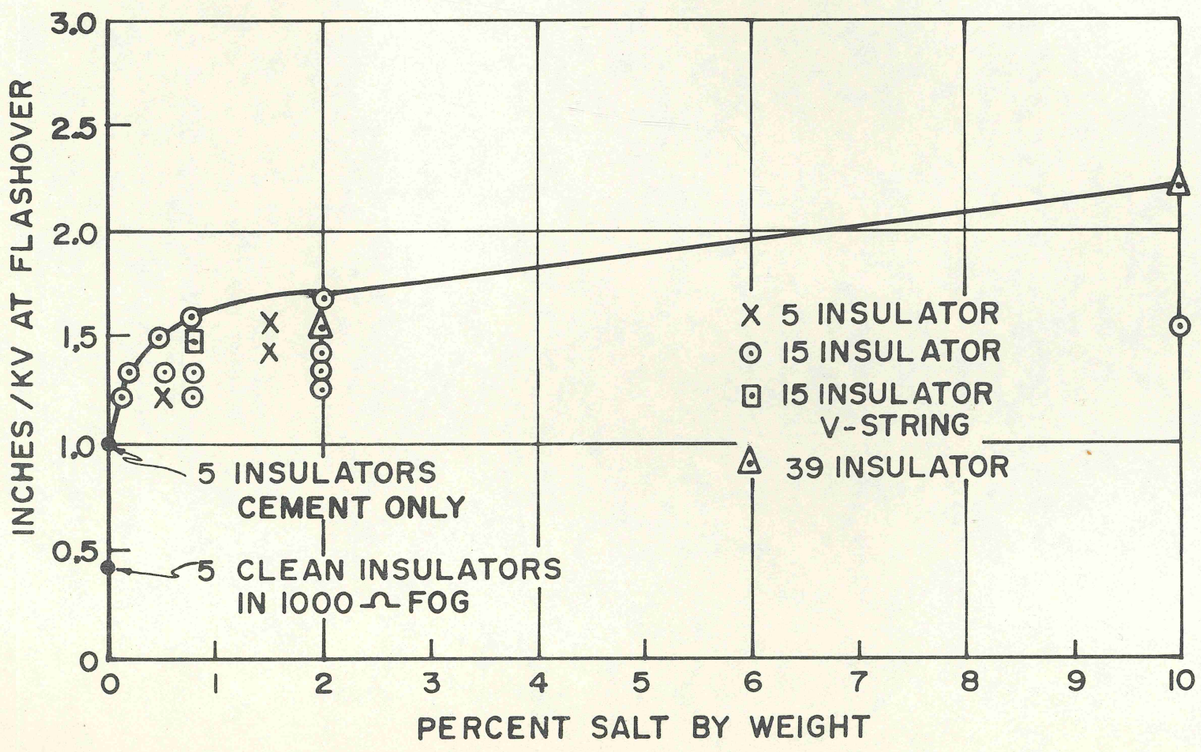


Figure 10. Inches of creepage per kv applied at 60 cycle flashover versus salt content of contaminant. Linear plot.

ALL VERT.

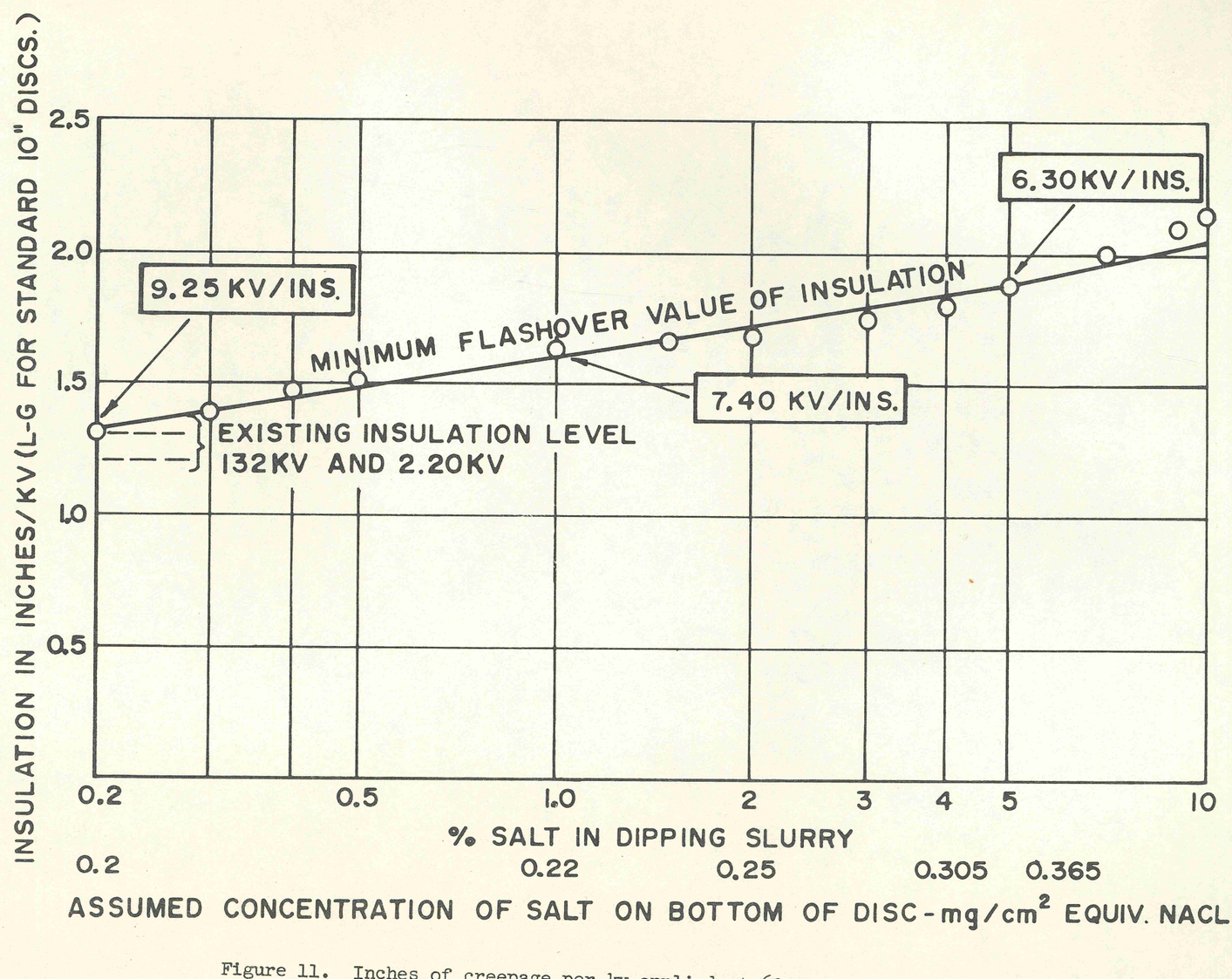


Figure 11. Inches of creepage per kv applied at 60 cycle flashover versus salt content of contaminant. Semi-log plot.

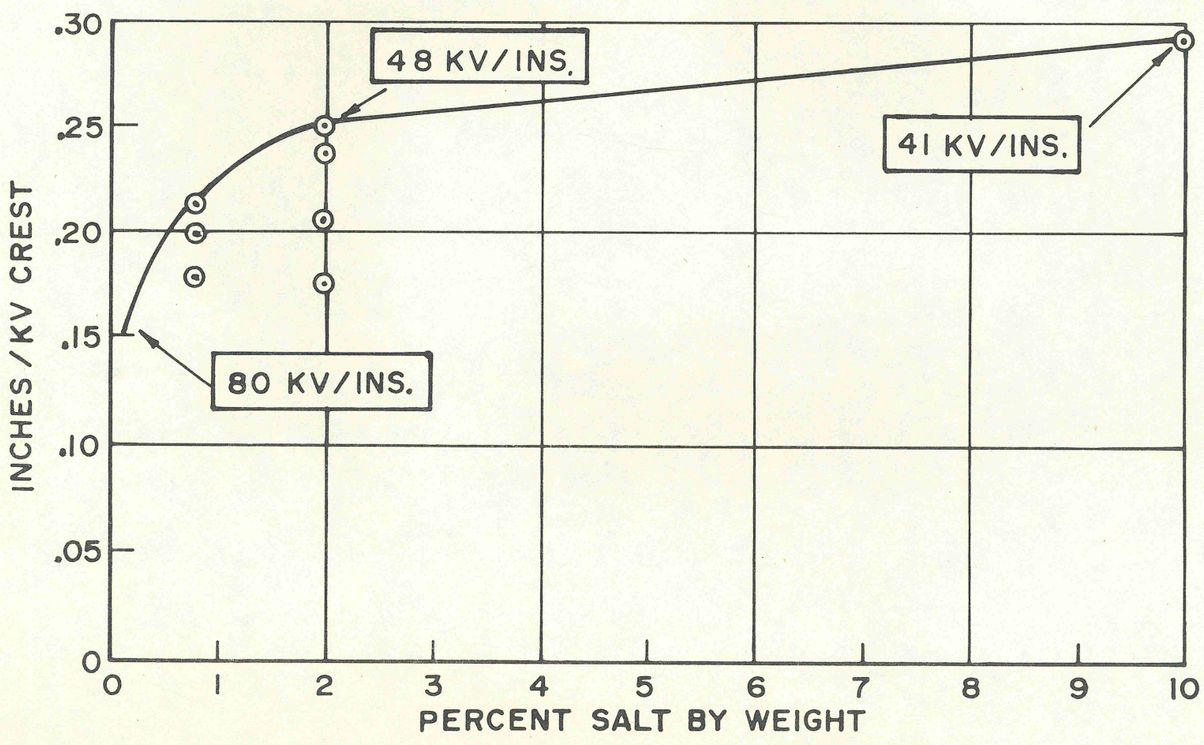


Figure 12. Inches of creepage per kv of switching surge withstand versus salt content of contaminant. All tests made on 15 vertical insulators with positive 140 x 3300 microsecond surges.

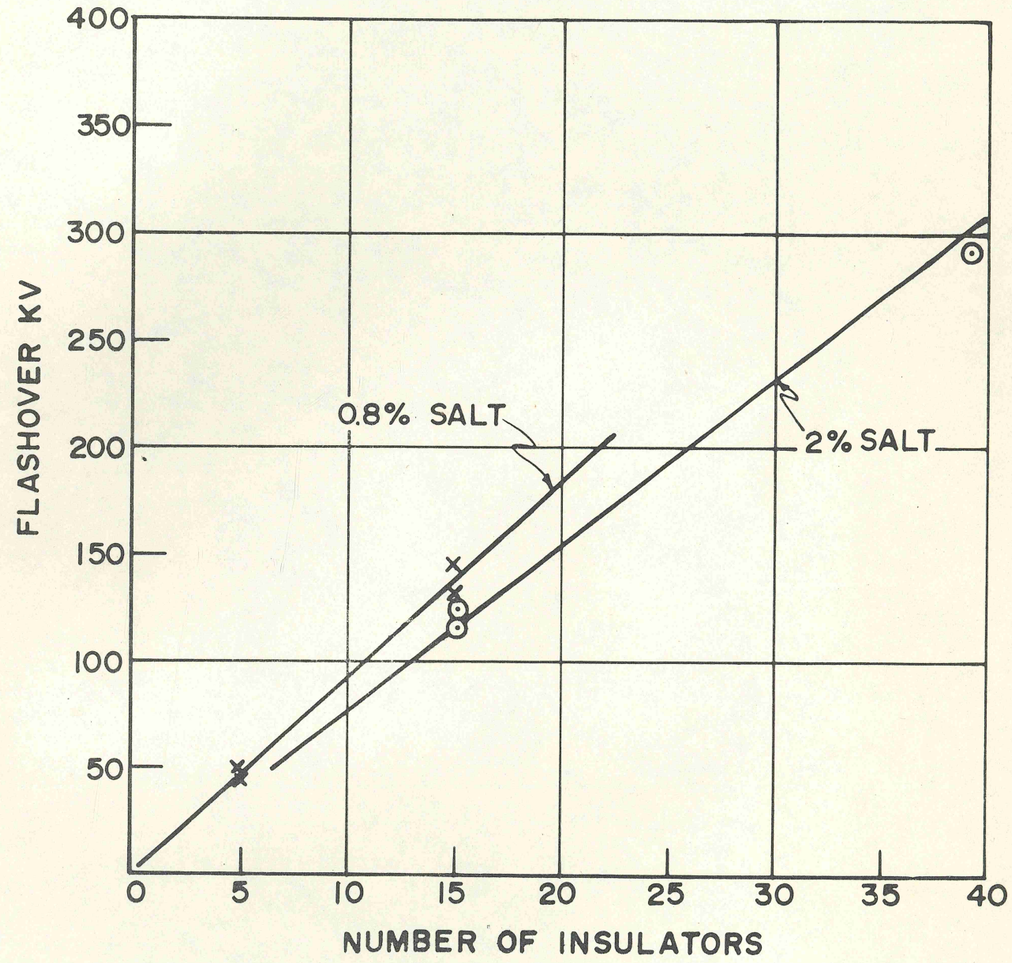


Figure 13. 60 cycle flashover level versus number of insulators for 0.8% and 2.0% salt contaminant.

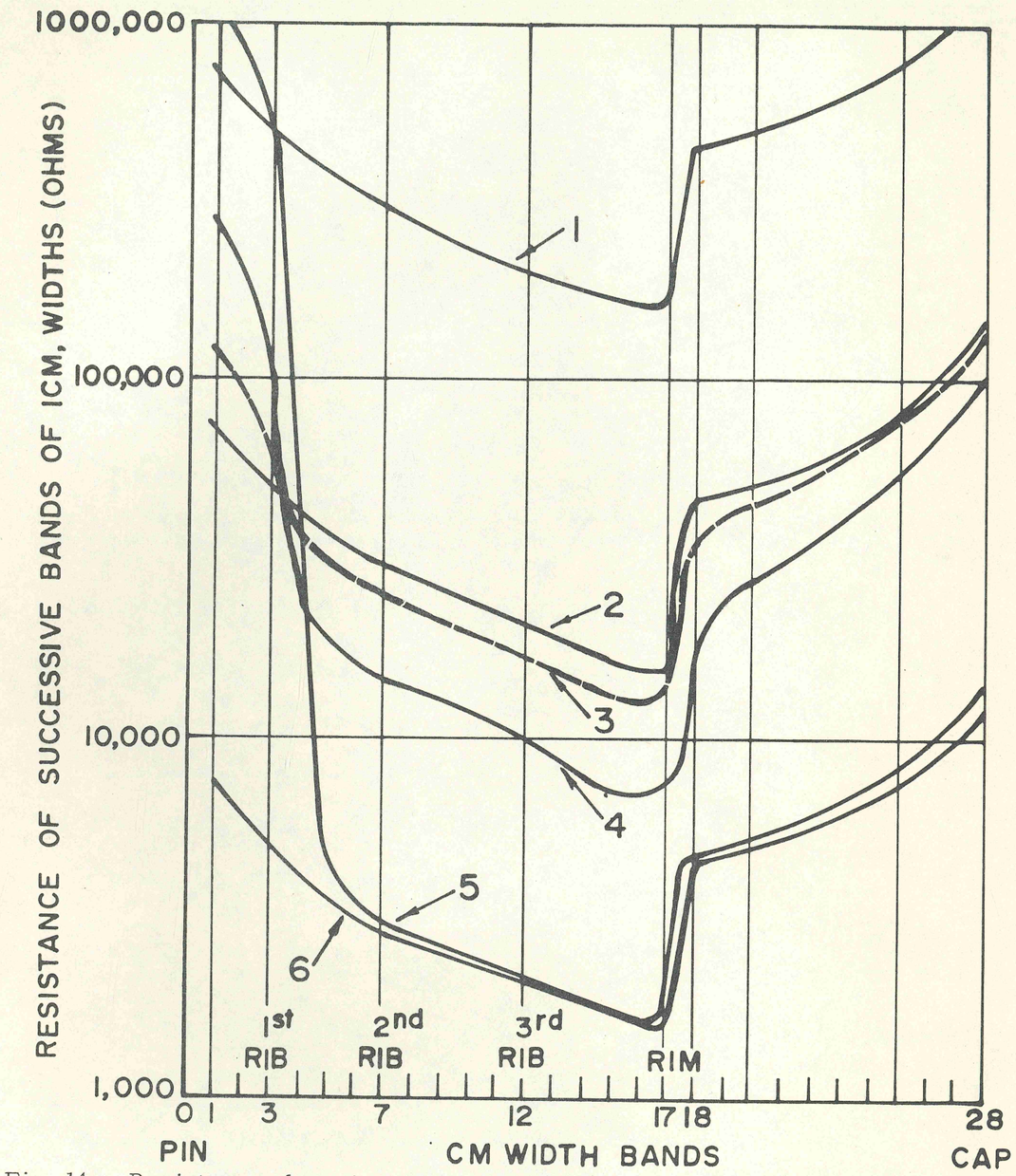


Fig. 14. Resistance of centimeter width bands on a contaminated insulator versus distance in centimeters from the pin (0) to the cap (28)

(1) Approximate dry pollution with no current.
(2) Partially wet resistance 8 minutes after fog start. No current
(3) Distortion by current heating in pin and cap area.
(4) Further distortion by accelerated heating in pin area.
(5) Prior to F/O. Very high resistance at pin. Current very low. Path away from pin tending towards fully wet resistance.
(6) Fully wet resistance, total approximately 130,000 ohms. No current.

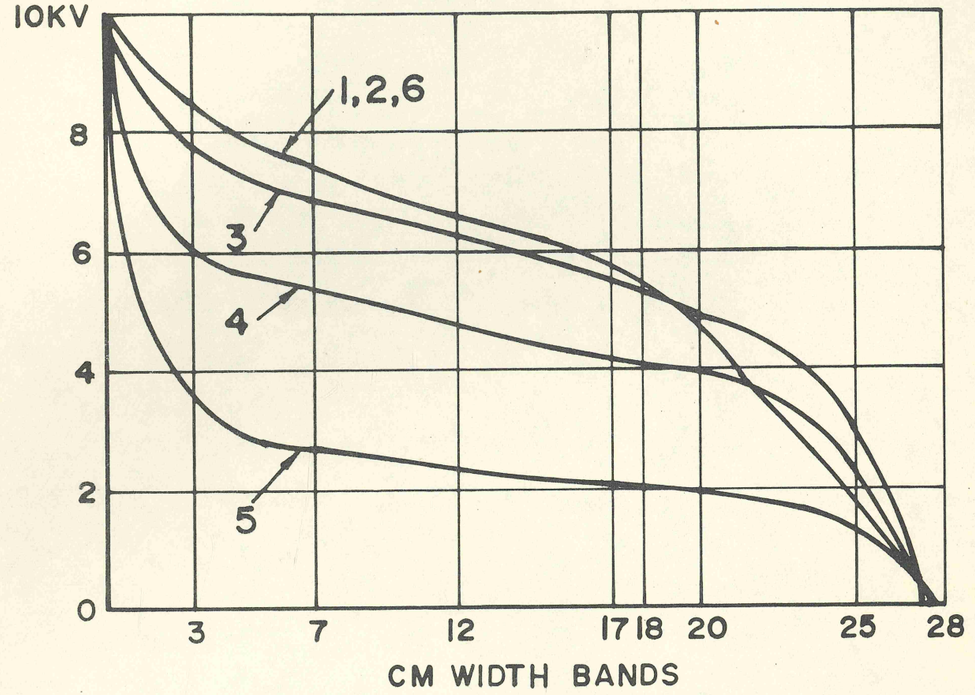


Figure 15. Approximate voltage distribution on contaminated insulators versus distance in centimeters from the pin (0) to the cap (28). Curve designations correspond to resistance curves in Figure 14.

ABSTRACT

The results of field and laboratory tests on contaminated insulators, made to determine insulation level of the S.E.C.V. 500 kv transmission system, are presented, including performance of 220 kv lines operating in a very heavy contamination area, field measurements of the pollution and insulator flashover mechanism, development of artificial pollution for laboratory tests, and the use of this pollution for power frequency and switching surge tests at the General Electric Pittsfield High Voltage Laboratory. Test data includes curves of power frequency and switching surge flashover levels versus contamination severity, power frequency flashover versus string length, and the results of high speed motion picture tests made to determine the basic mechanism of critical surging and flashover on contaminated insulators, plus a theoretical explanation of this mechanism:

KEY WORDS

Insulator contamination, transmission line design, EHV, 500 KV, 60 cycle flashover, switching surge flashover.

INSULATOR BEHAVIOR IN CONTAMINATED ATMOSPHERES

F.J.Turner
Senior Member IEEE
General Electric Co.
Pittsfield, Mass.

M.Kawai
Member IEEE
General Electric Co.
Pittsfield, Mass.

J.Kaminski, Jr.
Senior Member IEEE
General Electric Co.
Baltimore, Md.

INSULATOR BEHAVIOR IN CONTAMINATED ATMOSPHERES

INTRODUCTION

The conditions leading to flashover in contaminated atmospheres are very complex and do not always permit simple choices of insulator types for good performance. Increased understanding concerning performance under salt contamination has been realized, and reasonably good correlation between artificially contaminated insulators and pollution under natural environment is possible.

The authors wish to point out that pollution in industrial atmospheres is highly variable and needs much greater investigation and study.

It is generally accepted that contamination on the surface of an insulator results from the deposition of airborne particles. However further explanation of this process is needed to understand some of the difficulties involved in duplicating natural pollution with artificial pollution. At least two mechanisms can be involved, separately or simultaneously. The first is identified as mechanical contamination. Mechanical contamination is the manner in which salts are transferred to the insulator surface via wind borne aerosols or by aqueos contaminants deposited under moist conditions. Greater surface adhesion is expected under moist or damp conditions. Contamination by soluble salts particularly in coastal areas would be classed as mechanical deposition. A second mechanism is identified as chemical change. Contaminants formed by this method are not originally present but are chemical compounds formed by a chemical reaction initiated by airborne substances. For instance zinc sulfate has been found on insulator surfaces. This suggests that sulfur compounds (hydrogen sulfide, hydrogen sulfate, sulfur dioxide and sulfuric acid) under the influence of an oxidative agent (ozone) can react with galvanized surfaces to form zinc sulfate. While contamination by chemical change could occur in any location its effect would be most prominent in industrial areas.

The investigation attempts to follow two approaches.

1. Carry out a fundamental testing program to better understand the behavior of different insulator types under contaminated conditions.

2. Develop a practical acceptance test for all types of insulation, line as well as station.

Under the fundamental testing program artificially contaminated insulators are compared with each other and insulators from polluted environments are compared with artificially contaminated units.

DESCRIPTION OF TEST METHOD 1

During fog room tests at Project UHV, four insulator strings were usually tested in parallel each time. Small fuses (1/2A) were put in series with each string to cut it off from the energized line upon flashover. Although these fuses could not clear the arc, their complete disintegration when flashover occurred allowed the dropping of the test lead and reclosing of the circuit breaker within a half minute after tripping. Test voltages involved were 230 kV and 125 kV for these exploratory tests. Fig. 1 shows the inside of the fog room. Steam fog was generated by electric heating elements placed in tubs of water to produce a slow wetting condition. The leakage resistance of contaminated insulators in the fog room changed slowly.

Voltage was applied to the insulator strings before the start of fog generation. The steam fog filled the room gradually in 1 to 1-1/2 hours, and the whole test lasted about 2-1/2 hours.

For the fog room tests, the insulators were dipped in a solution containing kaolin of fullers' earth and salt. They were then dried by a hot air heater, or in the sun. The average salt deposit density on each insulator was measured by washing the under-surface of the insulators in a known amount of water and measuring the resistivity of this solution. Insulators with environmental pollution were tested in the same manner as the artificially contaminated units.

TEST RESULTS

Insulators with leakage distances ranging from 12-1/2 inches to 21 inches and with unit spacings from 5-3/4 inches to 9-5/8 inches were used on these tests. The type of units are shown on Figure 2 and characteristics appear in Table 1.

Figure 3 shows the relationship between flashover and salt deposit density with a coating thickness of 40 grams of kaolin per liter applied uniformly over the insulator surface. All flashover values have been reduced to standard unit spacings (kV $\div$ 5.75).

It is interesting to note that performance is not necessarily related to leakage distance alone. Insulator type D with 21 inches of leakage distance as compared to insulator (A), a standard ten inch disc, with 11-1/2 inches of leakage distance shows lower flashover levels. The conventional fog type insulator, type (E), with 17 inches of leakage distance as expected has higher flashover values than type A. Insulator type G also with 21 inches of leakage distance shows the best overall performance. This would then indicate the geometry of the porcelain can also be a significant factor in the flashover performance.

Examining the slopes of the curves, insulator A shows a rather steep slope at lower densities. Thus for slight increases in contamination large incremental changes in flashover voltages can occur. Unexplained behavior between insulator strings in the same general location , some flashing over while others sustain operating voltage, could possibly be explained by this flashover characteristic. The relatively flat slope of type G insulator would make is superior regardless of the degree of contamination.

The data in Figure 3 can be made more useful by relating it to expected insulator usage. The user wants to know how many insulators are needed and if a certain type is used what is the connecting length?

Table 2 shows these values at certain expected operating voltages, for both light and heavy contamination. The fewest number of units, 16 for 500 kV, as well as the shortest connecting length, 112 inches, are shown by type G. This shorter connecting length could be an important element in tower design. The final selection of insulator string lengths will also depend on wet switching surge performance.

A need to correlate the previous data with insulators polluted under actual operating conditions was recognized as being extremely important for practical application reasons.

The measurement of contamination on insulators sent to UHV Pittsfield for evaluation and analysis are shown on Figure 4. Areas 1, 2,3 and 5 represent industrial contamination. Areas 1 and 2 represent extremely heavy contamination possibly of mechanical nature and having flashover behavior quite different from that of normal salt atmospheres as shown by area 4. Thus the usefulness of Table 2 is limited to salt atmospheres and industrial atmospheres similar to area 3. Before greater correlation between artificial contamination and industrial contamination can be realized much more investigation and testing needs to be completed.

DESCRIPTION OF TEST METHOD II

In IEEE Transaction Paper 69TP14-PWR "A New Contamination Test Method" a modified wet contamination test is described in great detail. A brief summary of this test method is as follows:

The insulators are flow-coated starting at the top and working to the bottom with a stream of liquid that coats the complete surface to the point of run-off. Previous to the flow-coating operation the insulators are prepared by washing in a neutral detergent, rinsing with tap water, and drying with compressed air. It has been found possible to design apparatus to flow-coat large structures and the resultant coating has been found to be quite reproducible. The quantity of the coating, however,

in milligrams per square centimeter is somewhat less on the underside than on the top. This is also true of the dipping method and is probably due to the tendency to drip from the vertical surfaces. Furthermore, the flow-coating process can be carried on in any laboratory test area, and the residue flushed down the drain after test.

In the proposed "wet contaminant" test method the testing starts while the insulators are still wet, three to five minutes after the end of the flow-coating process. Although the objective of this test method is to determine the highest withstand voltage, initially a flashover is obtained to establish the voltage range. Therefore the voltage is brought up at a rate of about 7.5 kV/s to the flashover level, and the voltage recorded. A second test is then made repeating the whole washing, contaminating, and testing procedure except that this time an attempt is made to hold a withstand voltage tne percent below the flashover value. The complete test is repeated several more times until three withstands and no flashovers are received at some voltage level. This is then called the withstand voltage for the particular contamination level applied and is usually determined within five percent.

The above describes the method when used for development work to obtain design data. When used for a standard acceptance test method, one or more tests at the required withstand voltage can be specified.

There are two factors involved in this method that contribute to reproducible results. First, it has been found that with a little care the flow-coating nozzles can be shaped so that all of the insulator surfaces are covered to the point of run-off. The coating efficiency can be readily inspected by examination when wet, before applying the voltage, and also after the insulators have dried. Second, the flashover strength is dependent upon theamount of water held on the surface as well as the amount of solid materialdeposited. In the case of the "wet contaminant" method all tests are made with the surface completely wet.

The apparatus used to accomplish the flow-coating can be readily constructed from copper tubing. In Figure 5 is shown the apparatus used to coat suspension insulators. In this figure the contaminating liquid is pumped under pressure to the continuous copper ring which surrounds the insulators. On the inside surface of the ring 16 short sections of copper tubing about 6 mm in diameter (1/4") protrude. Half of these have a slight curve upward and sidewards so that the liquid is directed up along the grooves on the underside of the insulators.

The degree of contamination on the insulator surface can be measured in several ways. First, the amount of salt and binder in the flow-coating liquid can be specified. Second, since the contamination coating is not altered by the test, all or part of an insulator coating may be washed off in distilled water, the conductivity measured, and the amount of salt in solution determined by comparison with standard curves. The equivalent salt deposit density can then be computed. Third, before applying high voltage to the test specimen a low voltage can be applied, and the leakage current measured. The conductance can then be computed, and finally the surface conductivity can be calculated by multiplying the conductance by the form factor for the surface being investigated.

The form factor is not generally available and must be calculated from measurements made on a drawing of the insulator cross section using the formula

$$f = \int_0^{\ell} \frac{d\ell}{\pi D(\ell)}$$

where ℓ denotes the total length of the leakage path and $D(\ell)$ the diameter of each element of the leakage path.

Although the results obtained using this method (Figure 6)* show lower withstand levels than those under test method 1 there is no inconsistency in results. This test method was not intended to reproduce any natural pollution conditions. The

*(9 standard insulators and 8 fog type insulators per string used in these tests)

objective, to provide a relatively simple means for evaluating insulators is enhanced since minimum withstand levels will show safe margins below those that could be expected. The high degree of consistency as well as reproducibility as shown by Fig. 6 clearly demonstrates the value of this test method as an acceptance test. Also effective discrimination between designs as well as insulator types could permit writing specifications for contaminated applications.

CONCLUSIONS

1. When contamination by mechanical means, soluable salts, in the dominant factor in reducing flashover certain types of insulators show a marked superiority over others.

2. The criteria for good performance is not solely leakage distance. The geometry of the porcelain design can also effect flashover..

3. Expected operating performance can be predicted for different insulator types.

4. Artificial contamination cannot be reliably used to predict insulator performance under industrial contamination.

5. More investigation of industrially contaminated insulators is required.

6. A new type of contamination test method is being proposed that can be readily applied to all types of insulating structures and does not require highly specialized equipment or test facilities.

7. Although not attempting to reproduce any particular natural condition the wet contamination method can be used as an effective means in determining insulator specifications to be applied in any contaminated areas.

TABLE I

Type	Spacing	Diameter	Leakage Length	Mechanical Strength
A	5 3/4	10	11 1/2	30,000 lb.
B	6 1/4	11	14 1/2	50,000
C	7 3/4	12 5/8	16 3/4	66,000
D	9 5/8	15 3/4	21"	90,000
E	5 3/4	10 1/2	17	15,000
F	6 1/2	12 1/2	18 1/2	
G	7	12	21	40,000

TABLE 2

0.05 mg/cm^2

Type	115 kV	230 kV	345 kV	500 kV	765 kV
A	6 (34.5)	11 (63.5)	17 (98)	25 (144)	38 (220)
B	5 (31.4)	9 (56.5)	14 (88)	20 (125)	31 (190)
C		10 (77)	15 (115)	21 (163)	32 (250)
D			12 (115)	17 (165)	26 (252)
E	5 (29)	10 (57.5)	15 (86.5)	22 (127)	34 (195)
F		8 (52)	13 (85)	18 (117)	28 (180)
G		7 (49)	11 (77)	16 (112)	25 (170)

System voltage ÷ 1.732 for line to ground

0.1 mg/cm^2

115 kV	230 kV	345 kV	500 kV	765 kV
7 (40.5)	13 (75)	20 (115)	30 (172)	46 (265)
6 (38.5)	11 (69)	16 (100)	23 (144)	35 (220)
	11 (85)	17 (132)	24 (186)	37 (284)
		13 (125)	18 (174)	28 (265)
6 (35)	11 (63.5)	17 (98)	25 (144)	38 (220)
	9 (59)	14 (91)	20 (130)	31 (200)
	8 (56)	12 (84)	18 (126)	28 (192)

Fig 2

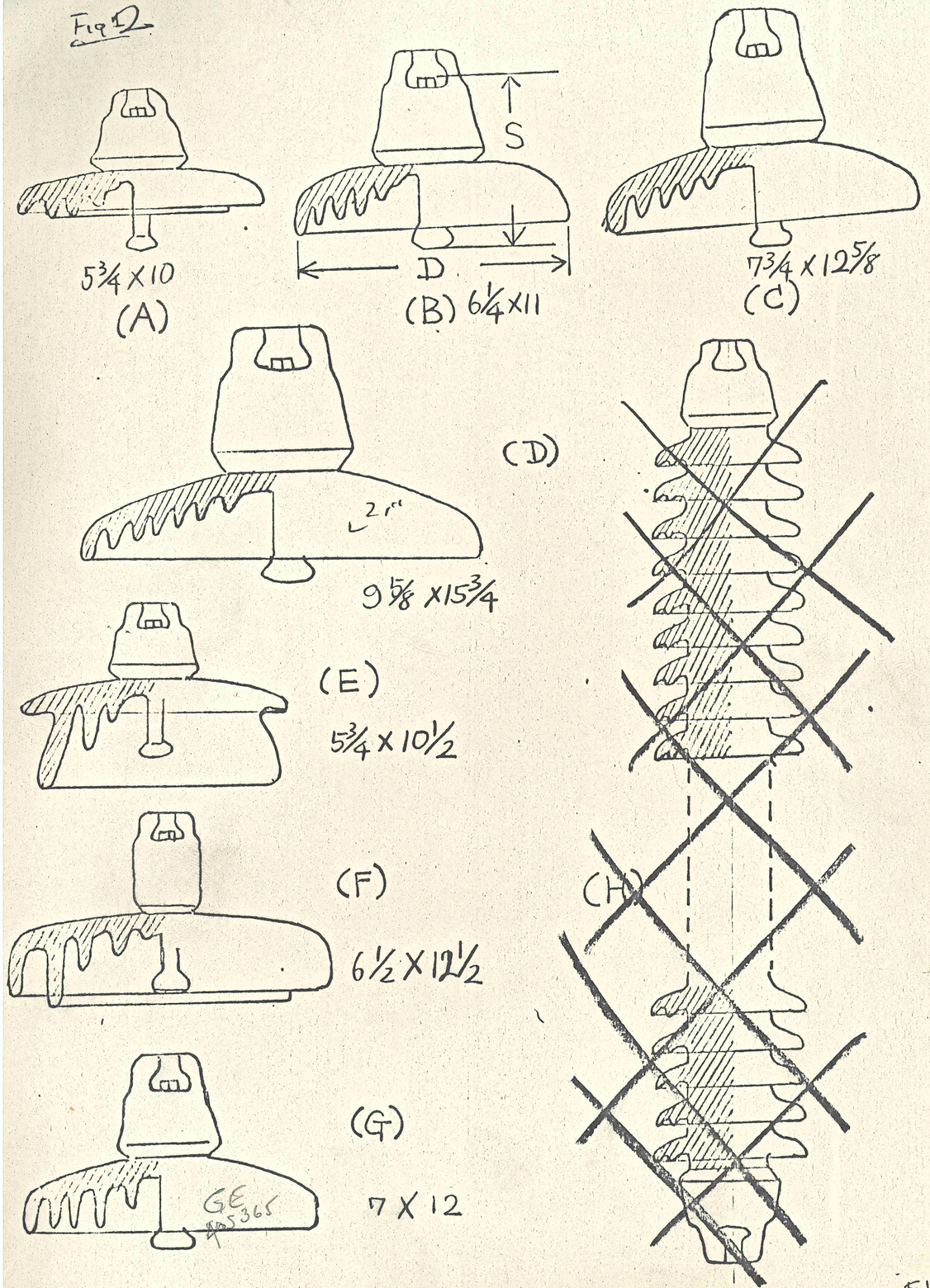


FIG 2

Fig 3

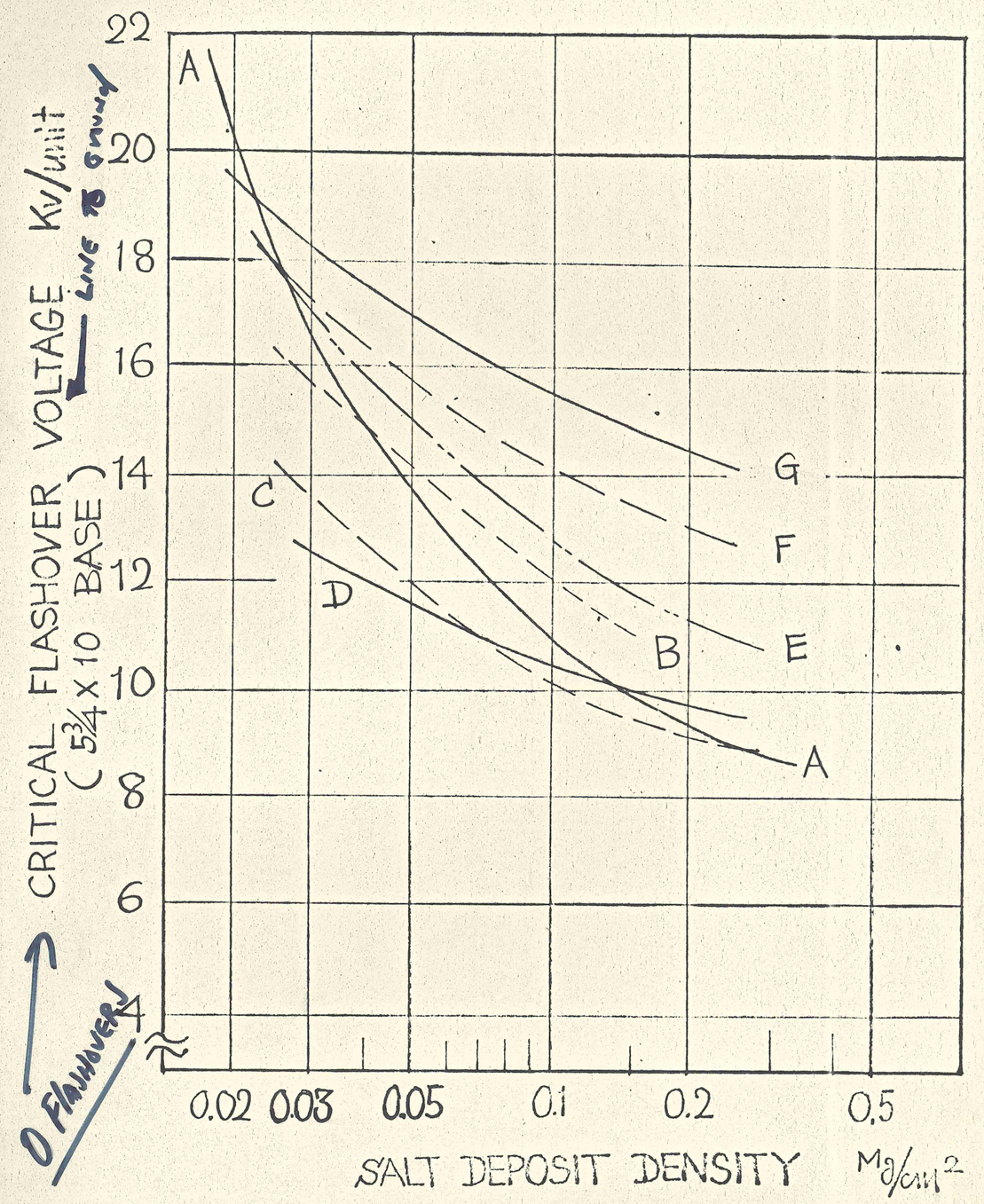


FIG 3

Fig.4

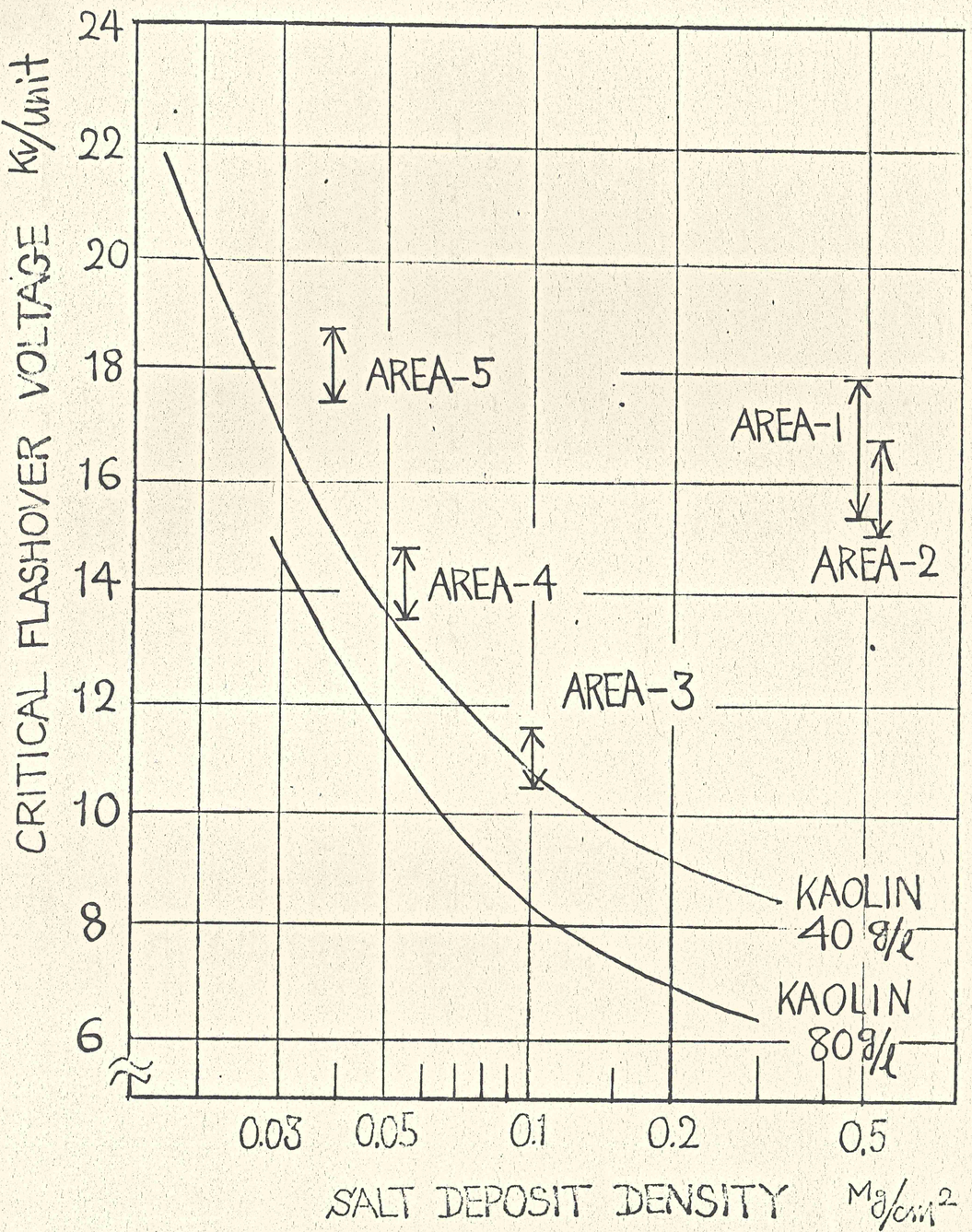
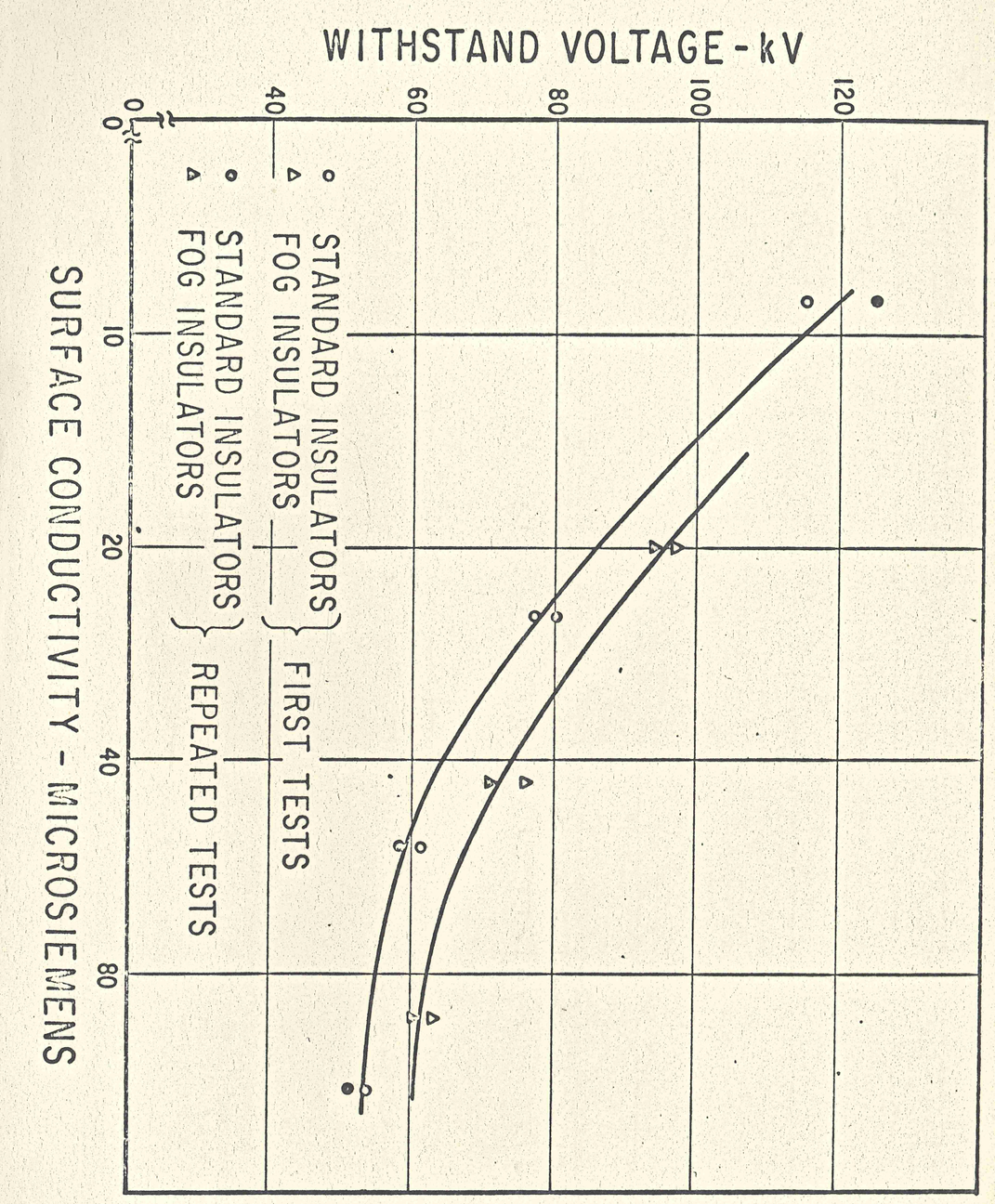

CRITICAL FLASHOVER VOLTAGE Kv/unit
24
22
20
18
16
14
12
10
8
6
AREA-5
AREA-1
AREA-2
AREA-4
AREA-3
KAOLIN 40 g/l
KAOLIN 80 g/l
0.03
0.05
0.1
0.2
0.5
SALT DEPOSIT DENSITY Mg/cm²

FIG 4


WITHSTAND VOLTAGE - kV
0
40
60
80
100
120
SURFACE CONDUCTIVITY - MICROSIEMENS
0
10
20
40
80
STANDARD INSULATORS
FOG INSULATORS
FIRST TESTS
STANDARD INSULATORS
FOG INSULATORS
REPEATED TESTS

STANDARDIZATION
OF
POLLUTION TESTS IN IEC TC 42

IEC TC 42, High Voltage Testing Techniques, has adopted the following clauses for contamination testing. These have been approved to be sent out to the National Committees under the six-months rule.

3.4 Artificial pollution tests

Artificial pollution tests are intended to provide information on the behaviour of external insulation under conditions simulating pollution in service.

The basic objective is usually to verify that the test object will withstand a specified amount of pollution at a given test or operating voltage.

For comparison tests and for research, the objective may be either to determine the degree of pollution that the test object can withstand with a given probability at a given test voltage, or to determine the withstand voltage for a specified degree of pollution. For comparison tests, the former procedure is preferable.

The procedure to be adopted must give reproducible results, taking into account the statistical nature of the flashover mechanism.

The result of an artificial pollution test is dependent mainly on the following factors:

- the installation of the test object
- the procedure for applying the pollution
- the amount, conductivity and distribution of the pollution
- the amount of moisture deposit
- the manner in which the test voltage is applied.

3.4.1 Test procedures

3.4.1.1 Installation

The test object should be tested in a position (horizontal, vertical or inclined) corresponding to actual working conditions. The clearance to entraneous structures (see Clause 3.1) need not exceed 1.0 S and may even be reduced below this, without affecting the validity of results, provided risk of flashover of the clearance is avoided.

The insulator shall be in thermal equilibrium with the air in the chamber at the start of the test. The ambient temperature at the start of the test shall be not less than 5°C or greater than 30°C.

3.4.1.2 Application of pollution

There is at present no standard or universally accepted artificial pollution test procedure but at least two different methods have been developed and are already in use to determine the performance of insulators subjected to pollution. The essential requirement is the repeatable production of various degrees or "severities" of pollution; this may be measured in terms of specific resistance or of some directly related parameter. Determination of performance, on the application of a suitable test voltage, is usually expressed in terms of the pollution severity.

The two techniques may be broadly described as the saline fog method and the predeposited pollution method:

a) Saline fog method

This is generally carried out by placing the test object in a special room which can be filled with a fog from a salt solution. The effect of simultaneously applying an appropriate test voltage while these conditions are maintained for a period of time are then evaluated.

In Appendix 1A, details are given of one saline fog technique.

b) The predeposited pollution method

The pollution is applied in a layer having approximately uniform thickness. It is usually a mixture of water, a non-conducting binding medium (for instance kieselguhr or kaolin), and a medium giving a controlled resistivity (for instance a metallic salt). The voltage is applied and the test object is wetted continuously with a fine water spray. Alternatively, the applied layer is so constituted that it retains sufficiently moisture for the duration of the test.

Procedure suitable for carrying out the predeposit pollution method is given in Appendix 1B.

3.4.2 Application of test voltage

Two procedures are in use for the application of voltage:

a) A constant voltage is applied to the artificially polluted test object for a specified time (generally in the region of 30 - 60 minutes) or until flashover occurs. In the case of the predeposited pollution method, the test may also involve the drying period which follows cessation of the wetting process.

b) A voltage of a specified value is applied and then raised at a specified low rate until flashover occurs. Several applications are made from which an average flashover voltage and a standard deviation may be determined.

Note: A flashover test with a rapidly increased applied voltage does not reproduce the same physical phenomena, involving the important thermal effects, associated with the application of a constant voltage (as in service).

APPENDIX 1A

DETAILS OF SALINE FOG TECHNIQUES

1. Cleaning

Before the test object is tested for the first time, the metal parts and cement should be painted with a corrosion-resistant paint, if found to be necessary, to ensure that no corrosion products contaminate the insulating surface during testing.

The test object should be washed with a suitable detergent to remove every trace of grease. Then it should be rinsed thoroughly with water of a high resistivity (more than 20 Ωm) to remove the remaining traces of any ionising material.

The surface of the test object is deemed to be sufficiently clean and free from any fat, grease, or any residuals if large continuous wet areas are observed.

2. Salt solution

The salt solution shall be made up to the required concentration expressed in g/l of solution from salt (NaCl) and mains water. It is recommended that the concentration be measured either by means of a hydrometer or a conductivity bridge with a correction for temperature.

It is recommended that the salt-solution concentration used should be one of the values: 2.5, 3.5, 5, 7, 10, 14, 20, 28, 40, 57, 80, 112, 160 and 226 g/l. The use of intermediate values may be justified in distinguishing between insulators of similar performance if their withstand salinities are low, or if carrying out a larger number of tests than that specified is considered justifiable.

The maximum permissible error in salt concentration is $\pm$ 5% of the nominal value.

3. Spraying system

The fog is produced in the test chamber by means of the specified number of jets (Figure 4), which produce a fine mist of the solution by a stream of compressed air flowing across the solution nozzle. The tolerances on the air and solution nozzles are as follows: internal $\pm$.02 mm, external $\pm$.05 mm. The ends of both nozzles shall be square-cut and polished. The end of the solution nozzle shall

lie on the axis of the air nozzle to within $\pm$ 0.05 mm and the maximum distance between the axes of these tubes shall be 0.05 mm. The pressure of the water shall be adjusted so that the flow of solution through each nozzle shall be 0.5 1/min. $\pm$10% for the period of the test, and the tolerance on the total flow to all jets shall be $\pm$ 5% of the nominal value.

Note that these requirements of the jet system for producing a salt fog differ considerably from those of nozzles used for wet tests.

The jets shall be in two pairs of columns parallel to and on opposite sides of the insulator which shall have its axis in the same plane as the columns, i.e. a vertical insulator will be tested with vertical columns and a tension insulator with horizontal columns. In the case of an inclined insulator the plane containing the insulator and the columns shall intersect the horizontal plane in a line at right angles to the insulator axis. The distance between the jets and the insulator axis shall be 3 m $\pm$5 cm for test voltages up to about 600 kV. For higher voltages larger spacings will be required. The jets shall be spaced at 0.6 m intervals, each jet pointing at right angles to the column axis towards its counterpart on the other column and within an angle of 1° to the plane of the sprays. This aim can be achieved for vertical jet columns by lowering the solution nozzle passing water through the air nozzle and directing it towards the opposing jet afterwards raising the water nozzle to the operating position. 10 or more jets per column are desirable, but as few as 5 are acceptable for insulators up to about 150 kV system voltage. The mid-point of the insulator shall be preferably in line with the mid-points of the columns of jets. Both columns shall extend beyond the insulator at both ends by at least 0.6 m. For vertical insulators, the bottom jets shall be 0.6 m above the floor of the chamber.

The jets shall be supplied with filtered, oil-free air at a pressure of 7.0 kg/m^2(4%).

4. Test procedure

The prepared insulator is installed in its test position in the test chamber and energized before the spray jets are started.

The salt-solution pump and air compressor are switched on, and the test is deemed to have started as soon as the compressed air has reached the normal operating pressure at the jets.

The object of an individual test is to determine the salinity of the fog which the insulator will endure without flashover for 60 minutes. A test with any one value of salinity therefore ends after 60 minutes or when the insulator flashes over.

APPENDIX 1B

DETAILS OF PREDEPOSITED POLLUTION METHOD

1. Cleaning and Installation

The same rules for cleaning and installation apply as in Appendix 1A. The insulators are then coated with a contaminating slurry and tested as indicated under 3 or 4 below.

2. Measurement of Pollution

The degree of contamination of the insulator surface can be specified in one or more of the following three ways.

a. The resistivity of the contaminating slurry.

This is best measured with a conductivity bridge.

b. The surface resistivity of the insulating surface.

This can be measured by applying a voltage of at least 2 kV/meter of total leakage path of the test object and measuring the leakage current of the test object. From these measurements the resistivity is determined. The lowest surface resistivity of a uniformly-distributed layer is then determined by dividing the insulation resistance by the form-factor f of the test object:

$$f = \int_0^{x_t} \frac{dx}{b(x)}$$

x = leakage path

x_t = total leakage path

$b(x)$ = circumference of the insulator

The formula is preferably evaluated by graphical integration. The surface resistivity ρ_s at the temperature t is to be referred to a reference temperature $t_0 = 20^{\circ}C$, according to:

$$\rho_{sto} = \rho_{st} \left(1 + 0.02\ (t - t_o)\right)$$

c. The equivalent salt deposit on the insulating surface may be determined by washing the pollution off of a specified area and dissolving it in distilled water. The amount of salt yielding the same conductivity when dissolved in the same amount of distilled water is considered as the equivalent.

3. Coating of the Test Object

A suspension is prepared which normally has the following composition:

100 g kieselguhr (Diatomaceous earth, diatomite)

10 g highly dispersed silicium dioxyd, particle size 2 - 20 nm (Aerosil) as thickening matter

1000 g water

Any other suspension or colloidal solution may be also used, if it has the same characteristic effects. In this case, the deposit on the surface of the test object should absorb about the same amount of water as when aerosil is used.

A specified resistivity of the suspension is obtained by adding a suitable amount of saturated calcium-chloride solution ($CaCl_2$) or sodium chloride (NaCl). For classifying the degree of pollution, the following values can be chosen with a tolerance of $\pm 15\%$ and referred to $20^{\circ}C$.

Suspension resistivity, Ωm	6.7	3.3	1.7	0.83
Layer resistivity, kΩm/m (completely wet)	200	100	50	20

The coating of the test object shall be effected by spraying this suspension on the clean surface of the test object using one or more spray nozzles, or suitable type of paint spray gun. The resulting layer should be so far as possible uniformly-distributed over the whole surface of the test object.

The coated test object should be uniformly wetted over its whole surface within about 15 to 30 minutes,using a steam fog generator or alternatively employing for nozzles such as shown in Figure 4 and 5 inserted in an arrangement corresponding to Figure 6. Compressed air flows through the nozzles and sucks normal tap water from a container. Each nozzle has its own open container so that the height H between the nozzle and the container remains constant. With constant air pressure, the quantity of fog produced by each nozzle is the same. The quantity of water can be varied by changing either the height H or the air pressure.

Columns with nozzles spaced at equal distances are placed around the test object. The progress of the wetting process is to be checked by measuring the insulation resistance as described in Item 2b above until its minimum value is achieved.

4. Test Procedure

The test voltage should be applied to the completely-wetted insulation when the minimum layer resistivity is achieved and the wetting process is continued as previously. The adjusted fog intensity should be kept constant during the test. Care must be taken to avoid water dropping from the sheds of the test object. The time of application of the test voltage should be at least 15 minutes.

If no dropping occurs, the test can be repeated with the same test object 4 times after drying after each single test. But only the first measured layer resistivity should be taken as reference.

5. Note

A variation of this method, described below, which does not require a fog spray is also in use. Acceptance of this is under consideration by TC 42.

A solution of a specified resistivity is prepared with the following composition:

20 g	pyrogenic silica ($Si O_2$)
1 g	photographic wetting agent
1000 g	water

Sodium chloride to obtain resistivity as listed above.

This solution is flowed on to the test object by means of an annular arrangement of nozzles each having an oval orifice approximately 1/4" x 1/8". The nozzles are directed inward with a tangential component so as to swirl the solution around the contours of the test object. This flow coating apparatus is moved slowly from top to bottom of the test object while the solution is pumped through the nozzles thoroughly wetting all of the insulator surfaces to the point of run-off.

A sufficient period (about 5 minutes) is allowed for dripping to stop and the coating to stabilize. The voltage is then applied and raised rapidly to the test level where it is held for a period of at least 15 minutes or until flashover occurs. For each test the test object must be washed, dried and recoated.

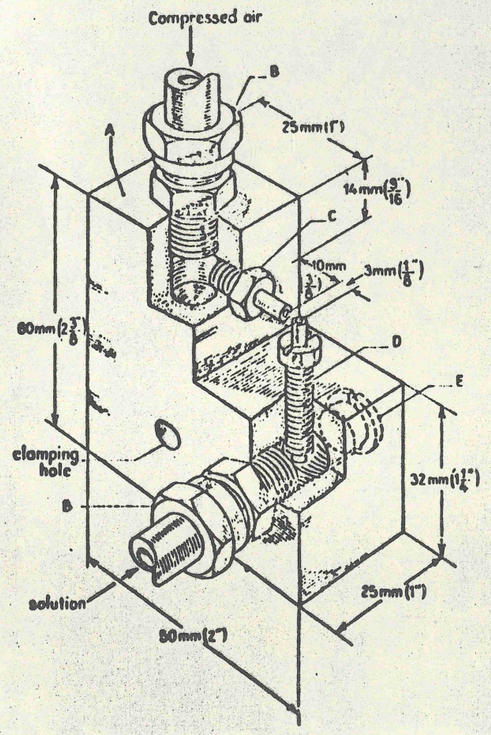


Fig. 4

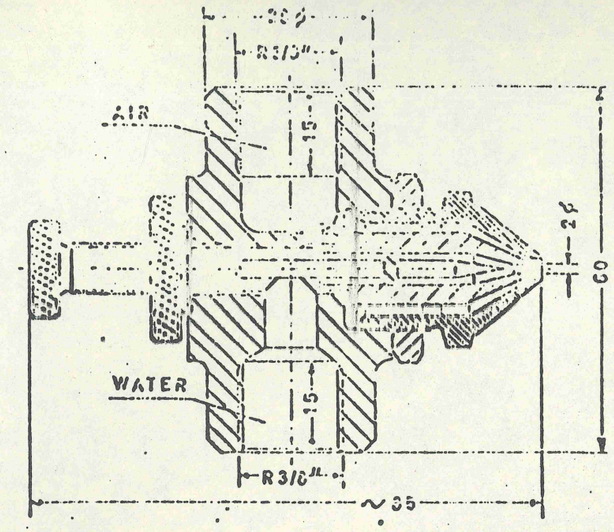


FIG. 5 LECHLER NOZZLE TYP Dr 112

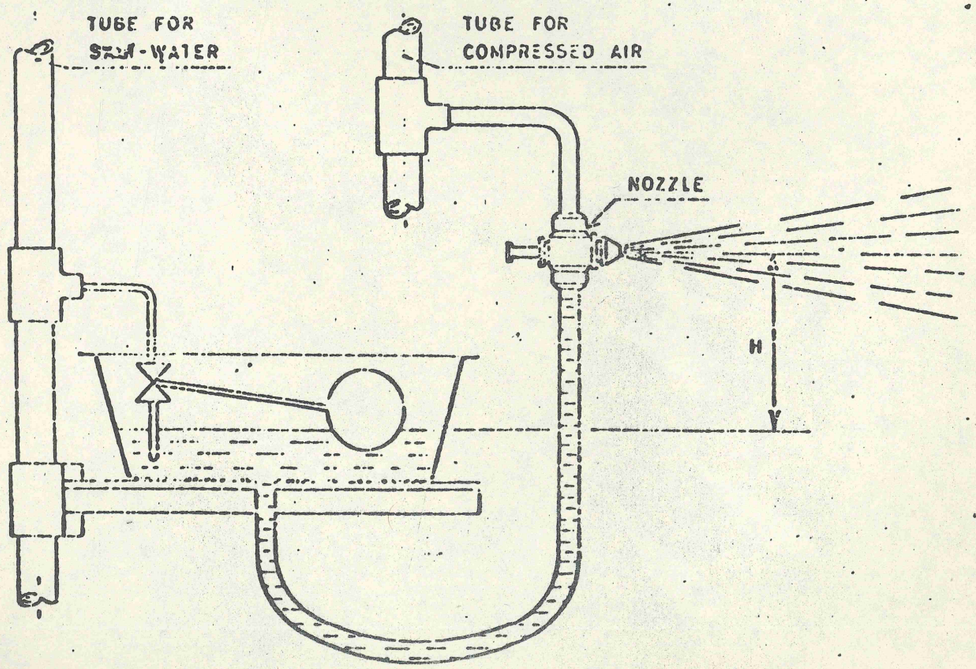


FIG. 6 ARRANGEMENT FOR PRODUCING FOG

Survey of Literature in 1968
by W.T. Starr

The state of understanding of the mechanism of flashover of polluted insulation is revealed by Zoledziowski's paper [1], and the discussion following it. Z. fits his data to the equation $(V^2-V_o^z)t = \frac{Ce}{3} r^2 L^3$ where V is the applied unidirectional voltage, V_o is the minimum voltage below which a flashover will not occur, t is the time to flashover, C is a constant, e is the energy needed for discharge production, r is the pollution resistance per unit length, and L is the distance between electrodes. Zoledziowski believes that the discharge propagates in air, not steam, that a dry band is not required for discharge initiation, and that the discharge starts to propagate at zero time.

Salthouse [2] has studied the processes which result in the initiation of dry bands on polluted insulators. Above a critical temperature rise (ΔTc) which is less than 1^oC, the resistance in one location increases much more rapidly than in others. ΔTc corresponds to a power dissipation density of about $5mW/cm^2$.

Kawai[3] has studied the natural conditions of humidity, fog and temperature which precipitate flashover and has determined withstand voltage of a variety of types of suspension insulators as a function of salt deposit density. Light rain or fog after several hours of high humidity minimizes flashover voltage. A steam fog artifically reproduces this condition.

Johnson et al[4] have reported on an intensive study of the conditions leading to flashover of heavily contaminated insulator strings leading to design criteria for a 500 kV line in Victoria. Contamination is by a salt laden smoke and fog, underside contamination controls. KV/insulator for 60 Hz flashover varies linearly with the logarithm of salt concentration being 1.3 in/Kv at 0.2 and 2.1 in/KV at 10 mg/cm^2. A mechanism is suggested and results of high speed motion picture corollation with surging currents are described.

Phelps, Owens, and Foti [5] have devised a contaminant and testing proceedure for evaluating insulator designs for EHV station use. A spray coating containing China clay, bentonite and salt is sprayed on the insulators to produce a deposit with a certain ratio of conductivity to thickness. After drying, the insulators are assembled in a salt fog chamber, thoroughly wetted and held at 1.1 X nominal line to ground for one hour. Then the voltage is increased and the flashover voltage noted.

Fujitaka et al [6] have developed a contaminant and test proceedure for pollution tests of insulators. The salt content of the contaminant is correlated with the amount known to exist in the application area. Power frequency voltage is increased to flashover in 30 seconds. Current available must exceed 5 amperes. Design data for station insulators are given as a function of ambient contamination.

Seven discussors [7] provide data on economic and technical aspects of live line washing of H.V. insulators as against greasing in polluted areas. Discussions of two papers, one favoring one approach and one the other are combined.

Niemi and Mitchell [8] describe a silicone plastic protective coating for suspension insulators to be used in polluted atmospheres. Excellent adhesion is claimed. The surface remains water repellent after UV aging. A 15 mil (0.375 mm) coating is being applied for field trials.

Billings and Storey [9] discuss two methods for determination of the effects of resistive glazes, pollution, dry bands, capacitor foils on the voltage distribution of insulators. One is a numerical method and the other is an electrolytic tank analogue. A resistive glaze can significanly decrease the tendency toward dry band formation despite its conductance being equal to (no more than) capacitive susceptance. Several interesting flux plots are included.

Ely and Roberts [10] examine the switching and impulse flashover of air gaps and insulators in a polluted atmosphere. Rod to rod and rod to plane gaps were not significantly affected. For insulators the 50% FOV dropped 240 kV for each 10 to 1 increase in salinity (35 X 2200 μs wave.) (10 unit standard disc or rod insulator)With prior alternating voltage energization, the FOV was considerably reduced (-60 kV with disc and -100 kV with rod). At a soluity of 5 g/l the FOV of the disc string is 600 kV while the rod type is 400 kV.

It is commonly assumed that the switching surge flashover characteristics of insulators and gaps are independent of pre-existing direct voltages. Watanabe [11] tested gaps and insulator strings with critical (50%) flashover (CFO) the range of 1 to 1.8 MV crest and a dc voltage of 400 kV. When the direct voltage was applied to same electrode as the surge, the effect was in the range of 2 - 7%, with neg. dc lowering positive surge CFO's and increasing negative switching surge CFO's. With positive switching surge, the effect is opposite. When the direct and switching surge voltages are applied to the different electrodes of the pair, the switching surge CFO was lower than without the direct voltage by an amount slightly less than the applied dc voltage.

Udo and Watanabe [12] have compared dry and wet sparkover characteristics of rod and sphere gaps and insulator strings with direct and 50 Hz voltage. Snow conditions on insulators are also included. Sphere and rod-rod gaps are essentially the same for direct and 50 Hz voltages. For rod-plane, positive and 50Hz crest sparkover voltages are similar. The influence of wet conditions is large for negative and small for positive rod. The direct voltage withstand of an insulator string is smaller for negative than for positive voltages and may be 50% of the dry value when wet and 25% when completely covered with snow.

For simplicity it is often assumed that the critical flashover voltage of a switching surge (S.S.) alone is the same as the c.f.o. for a s. s. superimposed on a 60 Hz. Udo, Tada and Watanabe [13] have evaluated this assumption and find that for a positive s.s. it is definitely true. This is fortunate for positive s.s. strength is lower than negative. Data are given for rod-rod, sphere to plane, bundle to tower. Data relative to humidity corrections and standard deviation are important also.

Paris and Cortina [14] have determined the influence of insulators in a large air gap on the switching surge and lightning surge flashover characteristics. Twenty electrode arrangements and four suspension insulator types were tested. For 1.2 X 50 μs negative polarity impulse, rod to plane and rod to rod gaps are most affected by the presence of insulators. For switching surges, the negative-wet combination in general is more affected by the presence of insulators than either negative dry or positive dry or wet. Sufficient data are given to cover a wide range of service conditions.

Okada and Kimoto [15] demonstrate how to improve the reliability of capacitance pin suspension insulators by applying a "proof" test to all porcelains and using those that pass for production. The proof test is mechanical stress resulting from applying hydraulic pressure into the cup of the insulator before the cap or pin is applied.

Taylor and Newport [16] examine the status of information and theory of the fracture mechanism of porcelain as it applies to suspension insulators.

Rogers [17] discusses the electrical and mechanical factors involved in the design of epoxy high voltage bushings. He includes two volt-time curves for epoxy compounds, one at room temperature and the other at 90°C. The asymptotic stress at 90°C is 270 volts per mil ($.10^4$-10^5 minutes).

Kappeler [18] describes the design and properties of resin bonded paper bushings for EHV applications. A major advantage over porcelain is the reduction of length of the end which dips into the transformer oil which is made possible by exposing the ends of the built in equalizers.

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Conference Paper

COMPARISON OF INSULATOR TYPES
BY THE
WET CONTAMINANT AND CLEAN FOG TEST METHODS

B. Macchiaroli
Inst. of Electrical Engineering
University of Naples
Naples, Italy

F. J. Turner
Senior Member IEEE
General Electric Company
Pittsfield, Massachusetts

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B. Macchiaroli*
Institute of Electrical Engineering
University of Naples
Naples, Italy

F.J. Turner
High Voltage Laboratory
General Electric Company
Pittsfield, Massachusetts

ABSTRACT

Withstand and flashover test data are presented for five types of insulators tested by the clean fog method and the wet contaminant method. The insulators were contaminated with a slurry having the proportions of 1 liter of water, 20 grams of Cab-O-Sil**, 1 gram of Photo-Flo**, and various quantities of salt to obtain the desired conductivities. The present data are also compared with those obtained by other investigators.

INTRODUCTION

In reference (1) the results of an investigation which culminated in the proposal of a new contamination test method were reported. Along with the proposed test, called the "Wet Contaminant Method", a new contaminating slurry composed of Cab-O-Sil**, Photo-Flo**, and salt was introduced. At the conclusion of the investigation, in order to further evaluate the new method, a large number of tests were performed to compare the withstand strengths of several types of insulators with both the "Wet Contaminant" and "Clean Fog" test methods. The new contaminating mixture was used for both testing methods.

The insulators tested were:

A. EIV high creepage glass disk, #67

B. Locke fog disk, Cat. #18134

C. Locke standard disk, Cat. #1840

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* - B. Macchiaroli was in the High Voltage Laboratory of General Electric Co., Pittsfield, Massachusetts on a NATO-CNR scholarship.

** - Trade name.

D. Richard Ginori fog long rod model 52486

E. Richard Ginori standard long rod model 52425

In each case the number of insulators was selected so that the overall lengths were roughly the same. Also, it was desired to use the same length of insulator strings as other investigators, (2) & (3), so that the data could be directly compared. The characteristics of the insulator strings tested are given in Table I and Figure 1.

The power sources used throughout the testing had short circuit currents of 10 amperes or more at the voltages employed.

TEST METHODS

Wet Contaminant Method:

The complete test procedure and the characteristics of the wet contaminant test method are detailed in a paper[1] by the authors so only the essential points will be summarized here.

The contaminating mixture used for the present tests is that which gave the best results in the former investigation, namely:

Cab-O-Sil	20 g/l
Photo-Flo 600	1 g/l
NaCl	2 to 20 g/l

For each test the insulators are washed in a neutral detergent, rinsed with tap water, and dried with compressed air. The insulators are then flow-coated with multiple streams of the prepared mixture that coat the complete surface to the point of run-off.

Three to five minutes after the end of flow-coating, while the insulators are still wet, voltage is applied and increased with a constant rate of 7.5 kV/s. In the first test the voltage is increased until flashover, whereas in subsequent tests an attempt is made to hold a withstand voltage below the preceding flashover level. For each withstand test the voltage is held at a predetermined level until current pulses and visual activity cease. The test is repeated several times until the highest level is determined at which three withstands and no flashover are obtained. This is called the withstand voltage for the particular degree of contamination and is determined within five percent.

The pollution degree can be measured in four different ways: by the salt content in the slurry, by the conductivity of the slurry, by the average salt deposit density on the insulators, or by the surface conductivity of the insulators.

In the present investigation, in order to have complete data for comparing the test results, all the above methods of measuring the pollution severity were used.

Clean Fog Method:

The concept of using a clean fog to deposit moisture on a contaminated string was first developed in Germany, and now is used in several other countries. However, although this method is being used by many investigators, the type of contaminant, the parameter for measuring the degree of pollution, and the test procedure are generally different.

For the present tests the same contaminating mixture was used as for the preceding wet contaminant method, but it was found necessary to use higher salt concentrations in order to achieve the same surface conductivities. This is due to the greater degree of "wetness" achieved with the wet contaminant method.

Before applying the contaminant to the insulators they were washed with a neutral detergent, rinsed with tap water, and dried with compressed air as before. They were then spray coated with the contaminant as uniformly as possible and allowed to dry. The dry string of insulators was then hung in a large tent made of polyethylene sheet material. This tent and the complete setup for the clean fog tests are shown in Figure 2.

Working with a spray system for contaminating insulators, and fog in a tent to wet them, there is necessarily a large number of variables. In order to reduce them to a minimum, conditions were held as constant as possible for each operation. The pressure on the spraying gun was maintained constant as were also the water and air pressure for the fog. These were 2 kg/cm^2 for the water and 6 kg/cm^2 for the air. Visibility inside the fog tent was less than three meters. The resistivity of the water used for the fog was 18,000 ohm-cm.

From preceding experimental work it was found that flashover data obtained in the fog tent correlated quite well with surface conductivity measure-

ments made just prior to applying the test voltage. These surface conductivity measurements were made by applying a low voltage and monitoring the leakage current versus time. Very erratic results can be obtained in this measurement unless some provision is made to insure a fairly uniform wetting of the insulators. It was found that this could be accomplished in two ways: 1) by exposing the insulators in the fog tent until the fog becomes dense and then spraying the dry areas with a hand spray gun using water having the same resistivity as that used for the fog, and 2) by placing a high speed fan in the corner of the fog tent directed so that it blows the fog up under the insulator skirts. Tests were made with both of these methods and it was found that they are roughly equivalent. In each case, the leakage current will rise to a maximum value at which it will remain steady for a period of time, and then slowly decrease due to the washing action of the fog.

Accordingly, in performing the present clean fog tests, an arrangement was made that allowed the conductivity to be measured for each insulator string. This was accomplished by the use of two power sources and a high voltage switch with which either source could be selected. Initially, the low voltage source was connected to the insulators under test, the fog turned on, and the leakage current monitored until it reached a steady value. At this time the switch was changed over to the high voltage power source, and the withstand or flashover test conducted.

For conducting the high voltage tests, the voltage was increased to some predetermined value, held constant for ten minutes, and then if no flashover had occurred, increased by ten percent and held for five minutes. If in the last voltage level a flashover occurred, the preceding level held for ten minutes was assumed to be the maximum withstand. If no flashover occurred, the insulators were cleaned and recontaminated and the test was repeated at a ten percent higher voltage. This process was repeated until the maximum withstand voltage was determined for a given surface conductivity.

The degree of contamination was measured in two ways: 1) by measuring the surface conductivity just prior to applying high voltage, and 2) by measuring the salt deposit density on the insulator surfaces both before and after test. There was an appreciable difference in the before and after

test results due to the washing action of the fog. Since, because of the test method adopted, an appreciable time elapsed with the fog on before the high voltage was applied, it was decided that the salt on the insulators after test was more representative of that present during the critical time of high voltage application; therefore, the "after test value" was the one recorded in this paper.

TEST RESULTS

Wet Contaminant Method:

The test results obtained with the five different kinds of insulators are summarized in Figures 3 through 6 in which the withstand voltage is plotted versus the amount of salt in the slurry, the conductivity of the slurry, the total salt deposit density, and the surface conductivity. The curves for the standard and fog disk units are from the preceding paper[1] by the authors.

For comparing different strings many criteria could be used. As stated in the introduction, the insulator string lengths were selected so that results could be directly compared with investigations (2) and (3). Therefore, for the same reason a voltage of 84 kV line-to-ground will be used to compare the ability of the insulator strings to withstand pollution. All of the measured values of pollution severity corresponding to a withstand voltage of 84 kV are recorded in Table II. In this table the insulators are listed in the order of merit, the electrically strongest one being first, and the ratios of the tabulated quantities for each insulator type to those for the strongest have been computed.

The order of merit of the insulators is the same regardless of which of the parameters is selected for measuring the degree of pollution. The ratios calculated vary somewhat going across Table II, but not to a significant degree, with two exceptions. These are for the salt deposit density on the long rods and surface conductivity of the fog and standard disk. The relatively superior performance of the high creepage glass disk to the fog disk on the basis of surface conductivity is hard to explain, since the salt in the slurry, the slurry conductivity and salt deposit ratios are in agreement. For some unknown reason the surface conductivity of the glass units became

greater than that of the porcelain for an equivalent salt deposit density.

In regard to the long rod insulators, the ratios for salt deposit density and surface conductivity are in agreement, but both are quite low in relation to the ratios for the slurry properties. This seems to indicate that the salt did not adhere as well to the long rod surfaces.

Throughout the testing it was observed that the long rod insulators behaved differently than the disk type. Whereas for the disk type insulators the variation in the surface conductivity for a particular slurry was 2%, for the long rod it was about 5%. Also the variability in the withstand and flashover data for the long rod insulators was very high; the flashover voltage varied as much as 40% for the fog type. Often, after obtaining a withstand value at a given level, a flashover occurred on a succeeding test at a level 10% or 15% lower. It was also noticed that the scintillation activity was different for the long rod insulators than the disk. Whereas for the disk type arcing starts off of the cap and pin, for the long rod there is activity between the skirts, and generally not on the body. Also, when attempting to hold a withstand level, a flashover may occur after several minutes, whereas with the disk type it usually occurs within a half minute.

The variable behavior of the long rod insulators was ascertained by a large number of tests, about one hundred total for the fog long rod. The final withstand values plotted on the curves are the highest levels at which three withstands were obtained below the lowest flashover voltage.

Clean Fog Method:

The effect of the two different methods of wetting on the withstand and flashover voltages is shown for each type of insulator in Figures 7 through 11, using salt deposit density as the measurement of pollution severity and in Figures 12 through 16, using surface conductivity as the pollution measurement.

Referring to the graphs it is seen that there is a greater dispersion in the results when plotted against salt deposit density than when plotted against surface conductivity. This is understandable, since the withstand strength is dependent upon both the amount of salt on the surface and the degree of wetness,

and both of these quantities also affect the surface conductivity. Even though the fog is maintained as uniform as possible, there is always considerable variation in the degree of wetness among the insulators of a string. The surface conductivity measurement inherently reflects this variability in wetness, and thus correlates quite well with the withstand and flashover values. The only exceptions to this were with the long rod insulators at low and high surface conductivity (about 15 μS and 70 μS).

Because the wet contaminant method can be performed in a short time, it was possible to make many replications. The clean fog method is much more time consuming and fewer replications were made. It is quite possible that if the same number of tests had been made for each method, there would have been better agreement at low and high surface conductivity.

The tests with the fan and those in which the insulators were wetted underneath by hand spraying gave about the same results. Evidently once the surface was thoroughly wet underneath by spraying, additional water was not required from the fog.

Sometimes there was an appreciable variation in the salt deposit density and surface conductivity among insulator strings contaminated by spraying with the same slurry. This reflects the inability of an operator to judge the thickness of the coating and is one of the reasons that the flow-coat method was adopted for the wet contaminant test. Originally it was intended to dip the insulators for the clean fog tests, but this was found to be impractical with fog type insulators because of the difficulty in attaching them together without damaging the coating.

In Figures 17 and 18 the curves for the various insulators are summarized for comparison. From these curves the values of salt deposit density and surface conductivity corresponding to a withstand voltage of 84 kV have been read and tabulated in Table III. As for the wet contaminant method, the ratios have been calculated with respect to the electrically strongest insulator, which is again the high creepage glass disk.

The order of merit of the insulators is seen to be the same when either the salt deposit density or the surface conductivity is used as a basis for comparison, but the ratios are quite different. As with the wet contaminant method, the high creepage glass disk insulators show a greater superiority

when compared on the basis of surface conductivity.

In Table IV are tabulated the average times that were required for the insulators to reach a steady value of surface conductivity. These times varied from test to test and generally increased with the amount of salt. It can be seen that the insulators with the most complex contours took the longest time to stabilize. Also the stabilizing times vary in the same order as the rating of the insulators by the wet contaminant method.

DISCUSSION OF TEST RESULTS

Throughout the tests, measurements were recorded of all the parameters affecting the degree of contamination so that they would be available for comparison both for the two methods investigated and also with the work of other investigators.

The order of merit of the insulators at a withstand voltage of 84 kV is listed in Tables II and III where it can be seen that the clean fog and the wet contaminant test methods result in the same ranking except for the fog long rod unit. In this case the wet contaminant method rates it fourth, whereas the clean fog method rates it second. As already mentioned there was a large dispersion in the data for the long rod insulators, and a large number of tests were performed with the wet contaminant method. This was not possible with the fog method, and this perhaps explains the difference.

This difference in performance of the fog long rod as evaluated by the two test methods existed over the entire range of test voltages as can be seen by comparing Figures 5 and 6 with 17 and 18.

In order to compare the severity of the two test methods, the salt deposit densities corresponding to a withstand voltage of 84 kV were summarized for the five types of insulators in Table V. It is apparent from these values that the wet contaminant method is the more severe of the two tests in that it requires a much lower salt density to reduce the withstand voltage to 84 kV. For the three types of disk insulators, however, there is a constant ratio between the two test methods indicating that they are really equivalent. The fog long rod and standard long rod insulators have different ratios which is probably due, as already mentioned, to the large variation in the data and the lack of time for making enough tests with the clean fog test method.

These same general observations also apply to Table VI where the insulators are ranked according to the conductivity corresponding to a withstand of 84 kV. There is one difference, however, in that the conductivities for a given type of disk insulator are practically identical for the two test methods, whereas the salt deposit densities were higher for the clean fog method. This can be explained as follows. The conductivity is dependent upon both the salt density and the wetness of the surface. Since the surface wetness is greater for the wet contaminant test, less salt is required to reach the same level of conductivity. Thus for a withstand value of 84 kV, it is possible to have the same conductivity measurement for the two test methods but have different salt densities.

Summarizing the results for the two test methods, it can be said that there is very good agreement between them in all respects for tests on the disk type insulators, but that the wet contaminant method rates the long rod insulators much lower than does the clean fog method. Among the disk units, the order is very much as expected with the high creepage glass first, the fog type second, and the standard third. It is possible that if a sufficient number of tests were performed by the fog method on the long rod units, they would also be in the same order as found with the wet contaminant method.

COMPARISON WITH OTHER INVESTIGATIONS

In references (2) and (3) results are reported for tests on insulators similar to those tested here except for the glass disk units. The insulators tested were of different manufacture, but had equivalent lengths, leakage paths and contours. In reference (2) both clean fog and salt fog tests were made, and in (3) the insulators were subjected to natural conditions. These data are summarized in Table VI for comparison with the present tests. Only the clean fog values are given from reference (2) since the salt fog tests resulted in the same numerical order.

Referring to Table VI, which gives the rank of the insulators as determined by the three separate investigations, it is found that there is very good agreement in the data from the CESI tests and the present tests, except for those on the long rod insulators obtained with the clean fog method in the present investigation. In the CESI tests the order is reversed for the

standard disk and fog long rod, but when the tabular values of conductivity are examined it is found that there is no real difference between the two. This is very interesting and important because it shows that results can be duplicated between different laboratories with different test methods and different contaminating mixtures when the surface conductivity is used as the basis of comparison.

Whenever a new contamination test method is proposed the final judgment as to its worth is the degree to which it can be related to results under natural pollution conditions. At the present time the only extensive data on various insulators available for natural pollution conditions are those reported from the test station at Brighton, England, where they are subjected to a highly saline atmosphere. At this station insulators corresponding to types B, C, D and E of this report have been on test first at 85 kV for 65 months and then at 85 kV plus 25%. During the first tests at 85 kV for over 5 years, both the standard and fog type long rod insulators flashed over. The tests were then continued at a 25% higher voltage on the disk units. According to the last report, the standard disk units flashed over after four months at the elevated voltage and the fog disk units were still running after eight months. These results are included in Table VI, and it is apparent that among the other data tabulated, those for the wet contaminant method agree most closely with the Brighton data. Accordingly, it may be concluded on the basis of present information that the wet contaminant test method will correlate well with service experience under seacoast conditions.

CONCLUSIONS

Two different test methods were used to compare the relative merits of five types of insulators coated with a contaminating mixture that was recently proposed in reference (1). Of the five insulator types selected, four similar ones were tested by other investigators [2,3]. As a result the following conclusions can be drawn.

1. The wet contaminant test method yields lower withstand strengths than the clean fog method on the basis of salt deposit density on the insulator surface. For disk type insulators, however, a constant ratio exists between the two methods.

2. Long rod type insulators behave differently than disk under contaminated conditions, and there is a wide dispersion in the withstand data. When the lowest values are considered, they are inferior to the disk type units according to the wet contaminant method and also some tests involving natural contamination. The fog type long rod, however, has been found stronger than both the standard disk and fog disk by the clean fog method. This could be due to the large dispersion in results and lack of a sufficient number of tests.

3. When surface conductivity was used as a basis for comparison, withstand and flashover values were duplicated for disk type insulators in different laboratories, with different test methods, and slurries with different binders. It should be noted, however, that a uniform contaminant coating method was used for all of these tests.

4. The numerical order of merit of the insulators when tested by the wet contaminant method is the same as that obtained in the test under natural contamination conditions in Brighton, England.

REFERENCES

(1) - B. Macchiaroli, F.J. Turner: "A New Contamination Test Method", paper presented for the IEEE Winter Power Meeting, New York, 1969.

(2) - G. Carrara, M. Sforzini: "Analysis of Pollution Test Methods", Conference Paper No. 68CP163 PWR, presented at the IEEE Winter Power Meeting, New York, 1968.

(3) - P.J. Lambeth, J.S.T. Looms, G. Leroy, Y. Porcheron, G. Carrara, M. Sforzini: "The Salt Fog Artificial Pollution Test", report presented at the meeting of CIGRE, 1968.

TABLE I

MAIN CHARACTERISTICS OF TESTED STRINGS

Insulator Type	No. of Units	Overall Length mm	Leakage Path mm
A. High Creepage Glass Disk	8	1320	3960
B. Fog Disk	8	1320	3450
C. Standard Disk	9	1314	2630
D. Fog Long Rod	1	1305	2840
E. Standard Long Rod	1	1270	1990

TABLE II

WET CONTAMINANT METHOD

COMPARISON OF INSULATOR TYPES AT A WITHSTAND VOLTAGE OF 84 KV

Insulator Type	NaCl		Slurry Conductivity		Salt Deposit		Surface Conductivity	
	g/l	Comp. With Insulator A	mS/cm	Comp. With Insulator A	mg/cm^2	Comp. With Insulator A	µS	Comp. With Insulator A
A. High Creepage Glass Disk	8.2	1	10.8	1	.050	1	50	1
B. Fog Disk	7.3	.89	9.6	.89	.045	.90	29	.58
C. Standard Disk	4.5	.55	6.4	.59	.034	.68	21	.42
D. Fog Long Rod	3.6	.44	5.5	.51	.016	.32	17	.34
E. Standard Long Rod	3.0	.37	4.5	.42	.014	.28	13	.26

TABLE III

CLEAN FOG METHOD

COMPARISON OF INSULATOR TYPES AT A WITHSTAND VOLTAGE OF 84 KV

Insulator Type	Salt Deposit		Surface Conductivity	
	mg/cm^2	Comp. With Insulator A	µS	Comp. With Insulator A
A. High Creepage Glass Disk	.070	1	49	1
D. Fog Long Rod	.064	.91	34	.69
B. Fog Disk	.062	.89	29	.59
C. Standard Disk	.048	.69	21	.43
E. Standard Long Rod	.040	.57	20	.41

TABLE IV

CLEAN FOG METHOD

AVERAGE TIME FOR REACHING A STEADY VALUE OF SURFACE CONDUCTIVITY

Insulator Type	Minutes
A. High Creepage Glass Disk	50
B. Fog Disk	45
C. Standard Disk	35
D. Fog Long Rod	25
E. Standard Long Rod	20

TABLE V

COMPARISON OF SALT DEPOSIT DENSITIES CORRESPONDING TO WITHSTAND VALUES OF 84 KV

Insulator Type	Clean Fog (mg/cm^2)	Wet Contaminant (mg/cm^2)	Ratio $\frac{\text{Fog}}{\text{Wet Contaminant}}$
A. High Creepage Glass Disk	.070	.050	1.4
B. Fog Disk	.062	.045	1.38
C. Standard Disk	.048	.034	1.41
D. Fog Long Rod	.064	.016	4.0
E. Standard Long Rod	.040	.014	2.86

TABLE VI

COMPARISON AMONG DIFFERENT INSULATORS

Insulator Type	Surface Conductivity Corresponding to 84 kV						Time to Flashover in Months	
	Wet Contaminant		Clean Fog		CESI - Clean Fog*		Natural Tests at Brighton**	
	µS	Rank	µS	Rank	µS	Rank	at 85 kV	at 85 kV + 25%
A. High Creepage Glass Disk	50	1	49	1				
B. Fog Disk	29	2	29	3	27	1	W 65	W 8
C. Standard Disk	21	3	21	4	18	3	W 65	4
D. Fog Long Rod	17	4	34	2	19	2	36	
E. Standard Long Rod	13	5	20	5	13	4	8	

* - Data from reference (2) - The values correspond to insulators having about the same characteristics.

** - Data from reference (3) - The values correspond to insulators having about the same characteristics.

W - Withstand

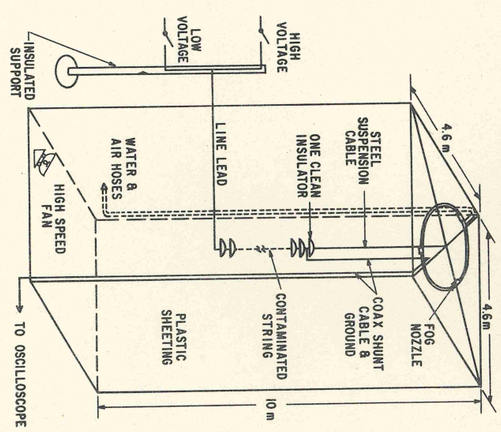

Fig. 2. Fog Chamber Arrangement.

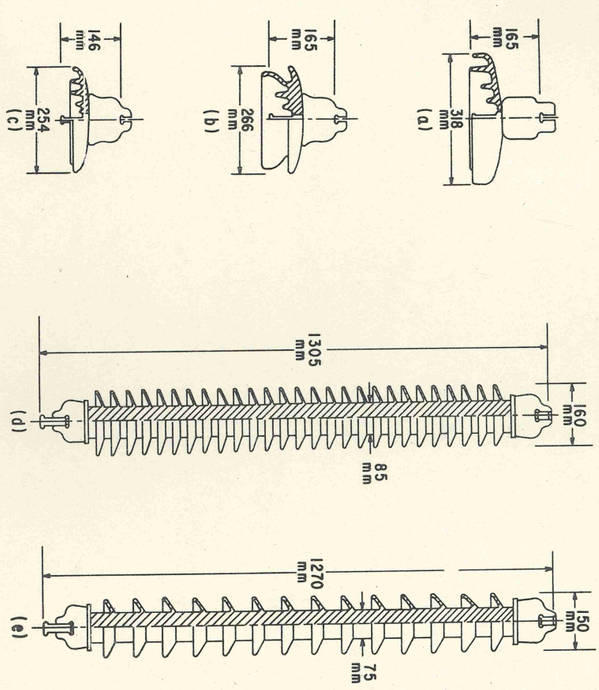

Fig. 1. Tested Insulators.

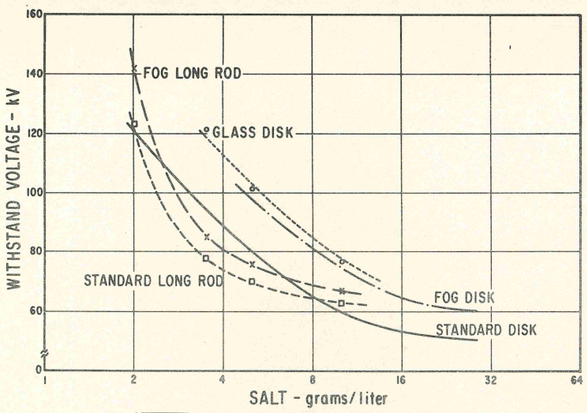

Fig. 3. Wet Contaminant Method - Withstand Voltage Versus the Salt in the Slurry for Disk and Long Rod Insulators. Fog and standard disk curves reproduced from reference (1).

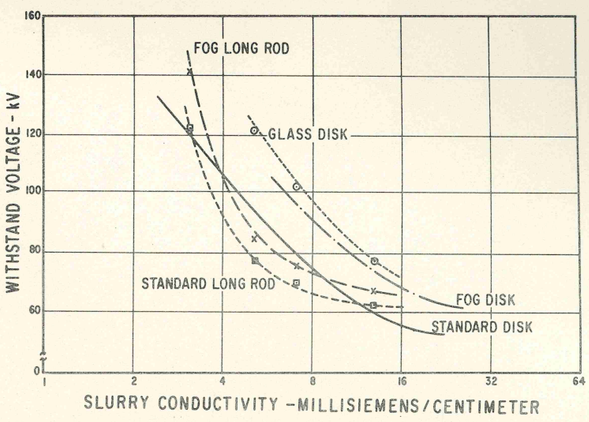

Fig. 4. Wet Contaminant Method - Withstand Voltage Versus Slurry Conductivity for Disk and Long Rod Insulators. Fog and standard disk curves reproduced from reference (1).

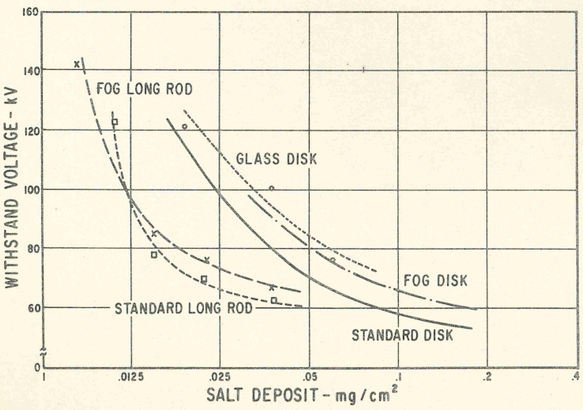

Fig. 5. Wet Contaminant Method - Withstand Voltage Versus the Salt Deposit Density. Fog and standard disk curves reproduced from reference (1).

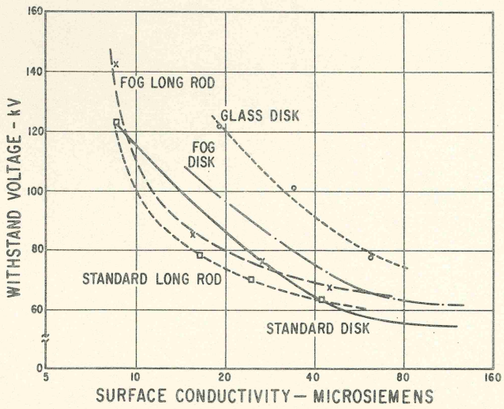

Fig. 6. Wet Contaminant Method - Withstand Voltage Versus the Surface Conductivity for Disk and Long Rod Insulators. Fog and standard disk curves reproduced from reference (1).

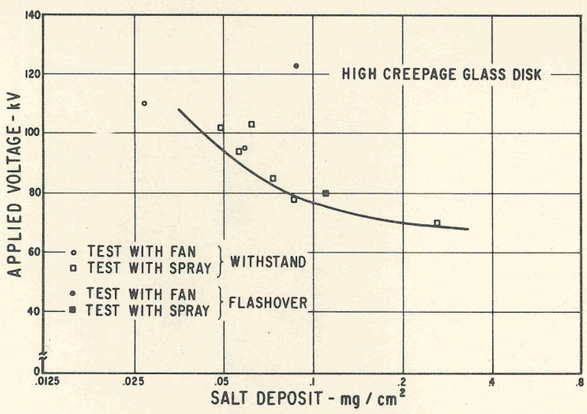

Fig. 7. Clean Fog Method and High Creepage Glass Disk Insulators - Withstand Voltage Versus Salt Deposit Density.

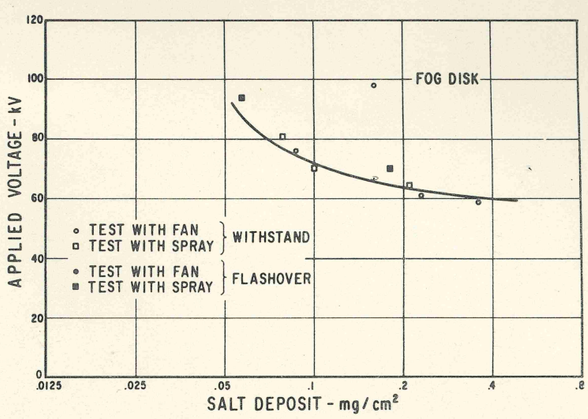

Fig. 8. Clean Fog Method and Fog Disk Insulators - Withstand Voltage Versus Salt Deposit Density.

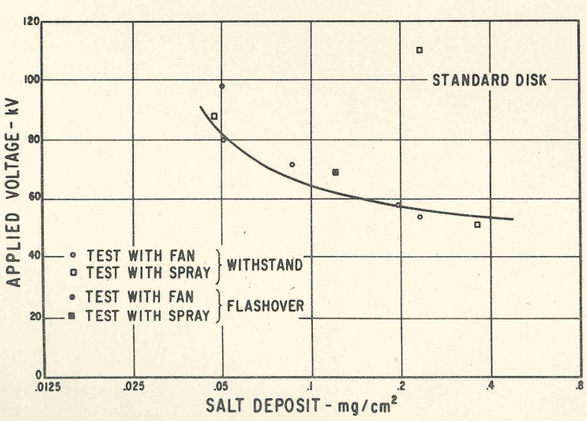

Fig. 9. Clean Fog Method and Standard Disk Insulators - Withstand Voltage Versus Salt Deposit Density.

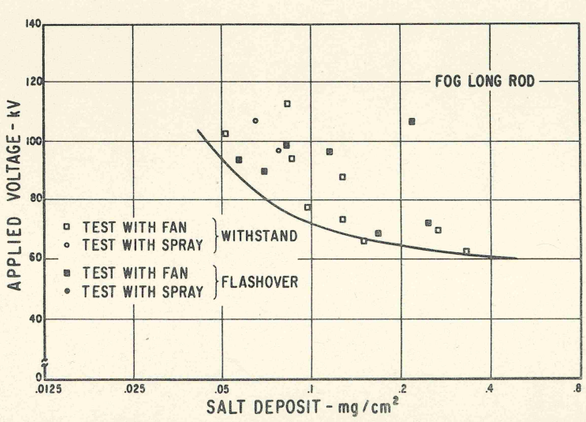

Fig. 10. Clean Fog Method and Fog Long Rod Insulators - Withstand Voltage Versus Salt Deposit Density.

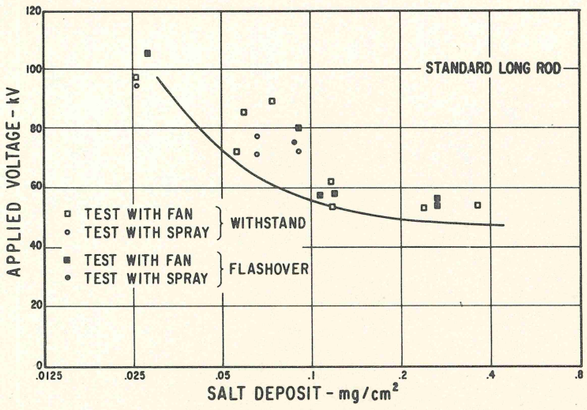

Fig. 11. Clean Fog Method and Standard Long Rod Insulators - Withstand Voltage Versus Salt Deposit Density.

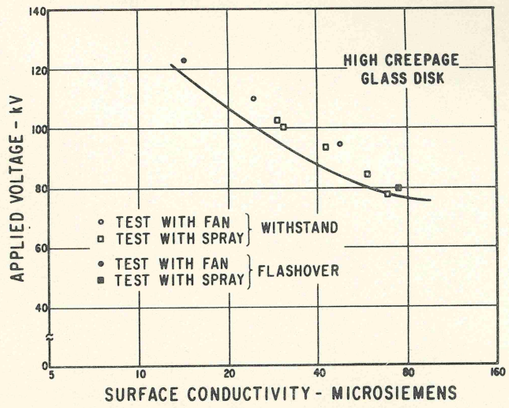

Fig. 12. Clean Fog Method and High Creepage Glass Disk Insulators - Withstand Voltage Versus Surface Conductivity.

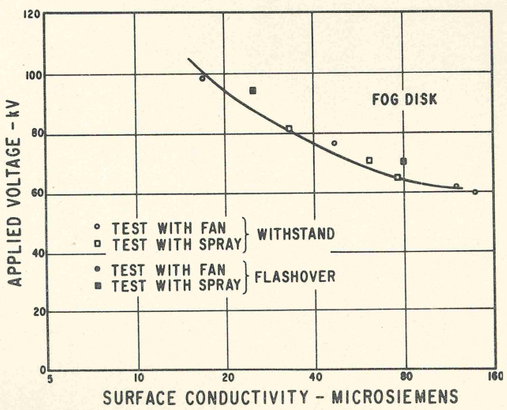

Fig. 13. Clean Fog Method and Fog Disk Insulators - Withstand Voltage Versus Surface Conductivity.

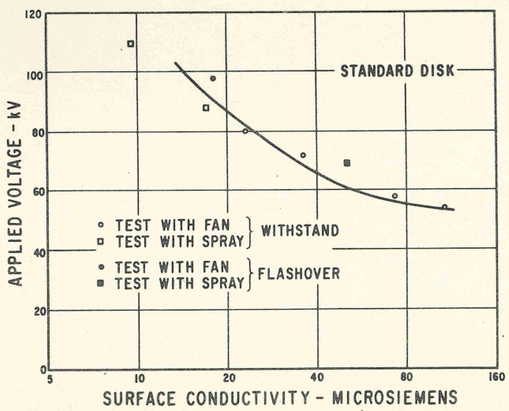

Fig. 14. Clean Fog Method and Standard Disk Insulators - Withstand Voltage Versus Surface Conductivity.

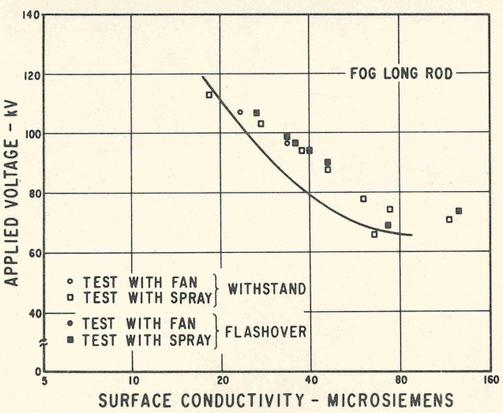

Fig. 15. Clean Fog Method and Fog Long Rod Insulators - Withstand Voltage Versus Surface Conductivity.

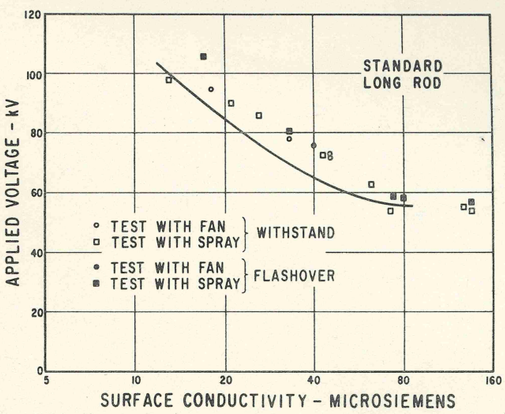

Fig. 16. Clean Fog Method and Standard Long Rod Insulators - Withstand Voltage Versus Surface Conductivity.

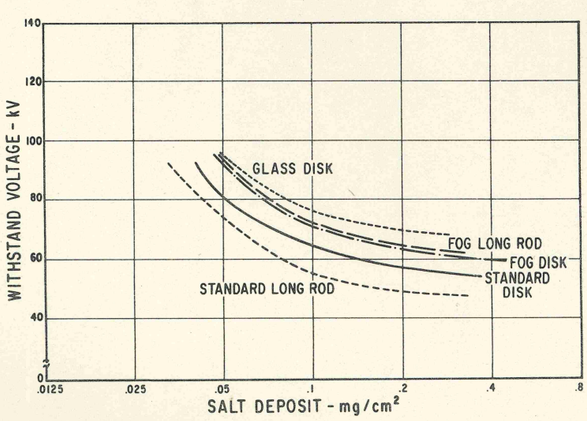

Fig. 17. Clean Fog Method - Withstand Voltage Versus Salt Deposit Density for Disk and Long Rod Insulators.

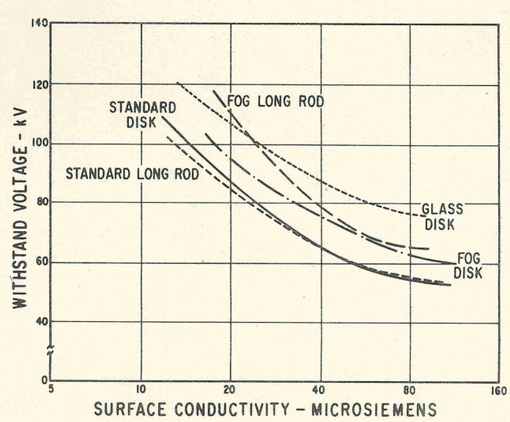

Fig. 18. Clean Fog Method - Withstand Voltage Versus Surface Conductivity for Disk and Long Rod Insulators.